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COMBINED SEWER OVERFLOW TREATMENT BY THE ROTATING BIOLOGICAL CONTACTOR PROCESS

Autotrol Corporation
Milwaukee, Wisconsin

June 1974

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16. Abstract A Rotating Biological Contactor (RBC) was constructed on a bypass of a portion of the combined sewerage in Milwaukee, Wisconsin, to demonstrate the feasibility of treating combined sewer overflows. Prior to actual field testing of this full scale RBC unit, simulated overflow tests were conducted with a bench scale RBC system to establish scale-up criteria for costing out the full scale plant, operating parameters and test conditions for the demonstration facility. Construction of the demonstration plant was completed early in 1969, and a full year of testing was completed in March of 1970. Average dry weather flow through the plant was 35 gallons per minute (gpm).

Under actual storm flow conditions, the demonstration plant exhibited system stability up to 14 times dry weather flow conditions. Beyond these conditions, COD treatment effectiveness sharply decreased ranging from no reduction at high flows to 79% reduction at normal dry weather flow. With lessening of these flows, biological treatment recovery was obtainable in 24 to 30 hours. To effectively treat these high overflow loads, sufficient volumetric storage and a solid separation operation should be provided to limit flow rates to controllable RBC treatment levels. (Tobin - EPA)

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17b. Identifiers

~~Rotating~~ *biological contactor (rotating), ~~wastewater treatment~~ *Milwaukee (Wis)

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June 1974

COMBINED SEWER OVERFLOW TREATMENT
BY
THE ROTATING BIOLOGICAL CONTACTOR PROCESS

by

AUTOTROL CORPORATION
Bio Systems Division
Milwaukee, Wisconsin

Program Element 1BB034

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ABSTRACT

A Rotating Biological Contactor (RBC) was constructed on a bypass of a portion of the combined sewerage in Milwaukee, Wisconsin to demonstrate the feasibility of treating combined sewer wastewater. Prior to actual field testing of this full scale RBC unit, simulated overflow tests were conducted with a bench scale RBC system to establish scale up criteria for costing out the full scale plant, operating parameters and test conditions for the demonstration plant. Construction of the demonstration plant was completed early in 1969, and a full year of testing was completed in March of 1970. Average dry weather flow through the plant was 35 gpm.

Under actual storm flow conditions, the demonstration plant exhibited system stability up to 14 times dry weather flow conditions. Beyond these conditions, COD treatment effectiveness sharply decreased ranging from no reduction at extremely high flows up to 79% reduction at normal dry weather flow. With lessening of these flows, biological treatment recovery was obtainable in 24 to 30 hours. To effectively treat these very high overflow loads, sufficient volumetric storage and a solids separation operation should be provided to limit flow rates to controllable RBC treatment levels

This report was submitted in fulfillment of Contract 14-12-24, Modification 9, between the Environmental Protection Agency and Autotrol Corporation.

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SECTION I

CONCLUSIONS AND RECOMMENDATIONS

The demonstration RBC plant at 8th and Montana has shown the process to be well suited to handling combined domestic and storm sewer runoff flows at and above design infiltration rates to interceptor and trunk sewers. The scope of the test program was not, however, wide enough to permit a full economic evaluation of the full potential of the Rotating Biological Disc Process for such applications. Nonetheless, from the observations and data collected in evaluating bench and scaled up-RBC systems, the following conclusions and recommendations can be made:

1. The RBC system has been shown to be very efficient in handling the normal dry weather flow. BOD reduction is high as 80 to 85%.
2. At the design storm level of 4 times dry weather flow, the RBC demonstrated a performance capability which was very nearly equivalent to that achieved under dry weather flow conditions.
3. RBC performance at the demonstration site not only confirmed results of bench and pilot plants, but displayed an ability to treat higher overload levels. Where pilot plant units demonstrated a capacity to treat hydraulic rates of 8 to 10 times dry weather flow levels, the Montana plant exhibited a capability to effectively handle storm runoffs of 14 to 20 times DWF for a period of 8 to 10 hours.
4. At very high hydraulic overloads (greater than 20 times dry weather flow) biolawn stripping of the discs is noted with a sharp decrease in RBC performance under continued periods of overload. However, with lessening or removal of this adverse condition, the RBC unit regained its full treatment capacity after 24 to 30 hours.
5. Peak overloads were usually very high and experienced in a short period (less than one hour). Flow hydrographs indicate that peak pollutant levels are sensed in the first 5 to 10 minutes of any rain event.

6. Rainfall data indicates an average of 0.46 inches per hour rainfall intensity for the demonstration area. The shorter rain events tended to have the highest runoff intensity, averaging 0.56 or higher. Whereas, the longest ones exhibited the lowest intensity at a median rate of 0.10 inches per hour.

7. Infiltration rates as high as 3000 gpm or 86 times the dry weather flow of 35 gpm were recorded. The median storm rate was 1500 gpm or 43 DWF.

8. Measured organic levels of the rain events indicated that the average rain event could increase the pollutant load 150 to 200% through the storm sewer system.

9. As indicated from test data, to optimize the RBC process, peak overflow loads have to be reduced by using a storage volume which will allow later treatment at controlled rates. Storage volume, in these instances, would always be less than the volume needed in conjunction with conventional treatment systems. The minimum capacity should be for at least a 20 minute volumetric period.

10. The biological treatment process converts soluble pollutants into solids and have to be followed by a means of removing such solids. In this regard, clarifiers have to be used with the RBC process. Utilization of clarification equipment could, however, effectively increase RBC capability to treat overloads ranging between 800 to 1000 DWF.

11. Conceptual design approaches to RBC storm sewer application would allow for upstream or downstream installation in storm interceptors and trunk sewer systems. Installation could be underground at chosen locations which would not seriously disrupt industrial or normal population activities.

12. As proposed, RBC approaches will partially, or completely, accomplish the following functions for reducing pollutants caused by combined sewer overflow systems; namely:

    - Provide temporary storage of discharge.
    - Ground water infiltration elimination.
    - Increase the hydraulic capacity of existing combined sewer systems.
    - Contribute to continual sewer flushing and cleaning.
    - Aerate the sewage and improve sedimentation characteristics of sludge during dry weather flow periods.
    - Produce a bacterial floc or seeding culture that will continue to degregate organic matter in the sewer or trunk lines downstream from the RBC installation.

Further studies are needed to establish the full economic merit of the RBC process for this application, both in terms of comparison to other alternative combined sewer approaches, but also the competitive impact of using current advance RBC technology. Optimum use of rain peak storage, solids separation, overall system design to optimize the economics will, likewise, require further analysis, and perhaps complete prototype testing to fully verify a final plant design concept.

SECTION II

INTRODUCTION

BACKGROUND

The combined storm water and sanitary waste collection systems of more than 2,000 communities in the U.S., serving a total population of around 60 million people, discharge into rivers, streams, lakes, and bays during and after heavy rains.

When the total rain flow exceeds the hydraulic capacity of the community sewage treatment system, storm spillage too often becomes intolerable, causing an alarming amount of pollution to the receiving bodies of water.

The estimated cost of completely separating all the sanitary waste and storm water systems in this country is prohibitively high -- greater than $30 billion.

One conceptual approach to treating combined storm overflow waste was identified as the rotating biological contactor or RBC process.* In February, 1967, the FWQA elected to sponsor a test program evaluating the use of RBC process for storm sewer overflow applications.

---

* The term RBC was originally applied to the Rotating Biological Contactor process at Allis-Chalmers Mfg. Co., Milwaukee, Wisconsin. Autotrol Corporation of Milwaukee, Wisconsin, purchased the RBC business from Allis-Chalmers in 1970. The process is now termed the BIO-SURF process. For purposes of consistency, documentation, and continuity of published reports, the term RBC is maintained throughout this report. Again, in this report, nomenclature for Allis-Chalmers is equivalent to Autotrol.

SCOPE

The purpose of the FWPCA Contract (No. 14-12-24) was to demonstrate the feasibility of employing the rotating biological contactor process for the in-line treatment of combined storm and sewer waste.

Phase I consisted of preliminary design, initial cost analysis, and laboratory testing of a 10-stage, small-scale pilot plant. Specifically, Phase I tasks included:

Task I	Site selection for the larger demonstration facility.
Task II	Simulated rainfall testing with the 10-stage pilot RBC.
Task III	Preliminary design and cost analysis for the demonstration plant.

Phase II included the final design and construction of the demonstration plant. For planning purposes, this phase also included demolition and site restoration.

Phase III covered operating the demonstration plant and subsequently updating the full-scale plant design and cost estimates. The total program was scheduled for a period of one year, beginning May, 196[illegible].

THE ROTATING BIOLOGICAL CONTACTOR (RBC) PROCESS

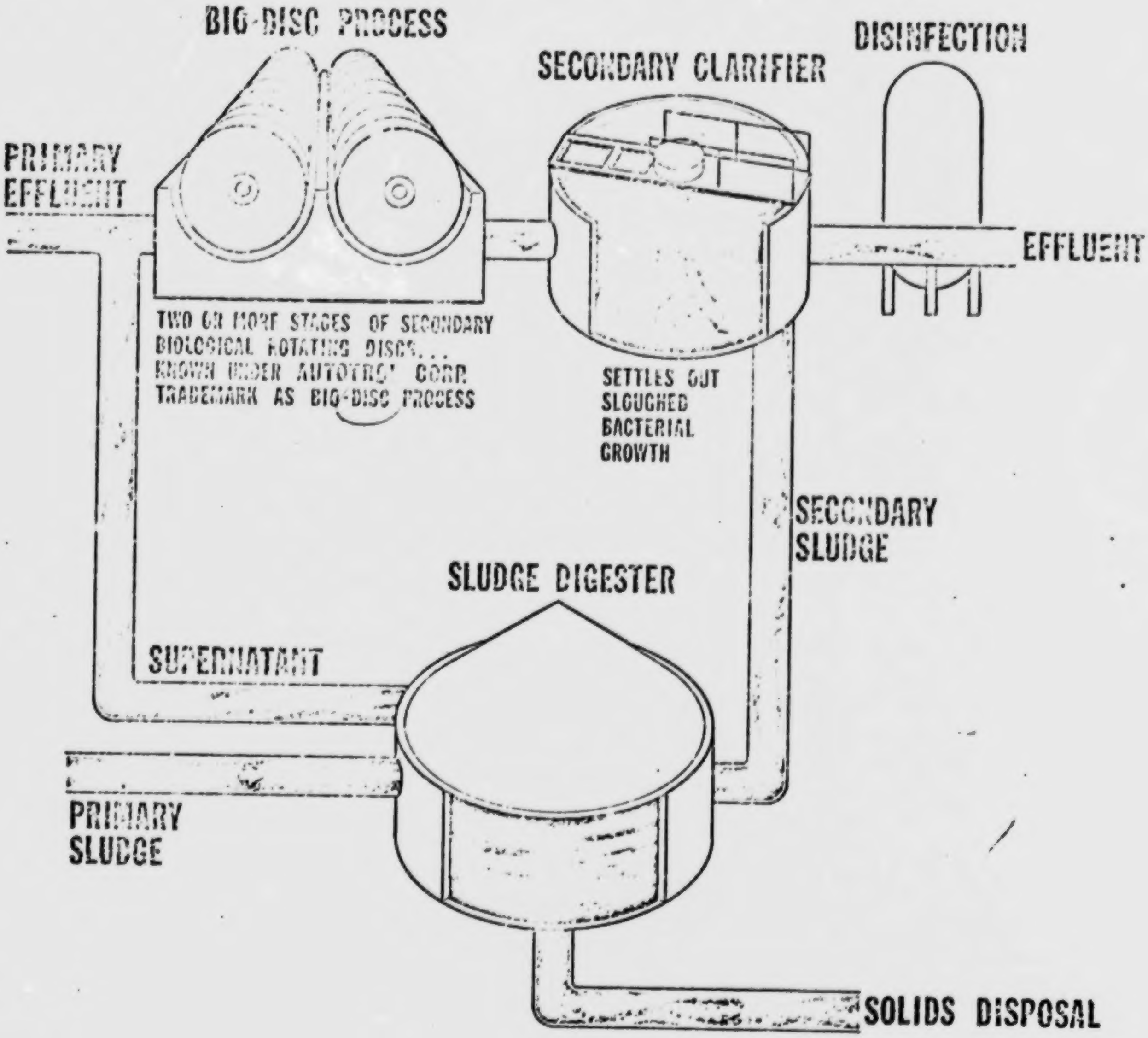
The Rotating Biological Contactor process consists of a series of closely spaced discs, or similar fixed surfaces, which are mounted on a shaft and rotated while partially immersed in wastewater. As the discs rotate (Figure 1) alternately in the wastewater and surrounding air, a biological growth forms on the disc surface, which, on immersion, picks up a thin film of wastewater, and on emerging absorbs oxygen from the air and organic materials from the wastewater film.

With each rotation, the film of aerated and partially treated wastewater is mixed with the substrate of the tank containing the discs. The continuous rotation also replenishes the dissolved oxygen content of the main body of wastewater. At the same time, the concentration of the organic material of the wastewater is reduced in the tank. The thickness of the aerobic growth developed on the surface of the rotating discs is regulated by the penetration of the oxygen to the deepest microorganism layer and by the concentration of the organic matter in the wastewater. Part of the organic matter is oxidized; another portion is synthesized into additional biomass; and some is stored in the biomass for oxidation and synthesis at a later time.

Rotational shearing forces cause sloughing of excess biomass. The rotation induced turbulence of the discs keeps these sloughed solids in suspension, and the flow of wastewater transports them from the disc units to subsequent clarification steps for separation and disposal.

FIGURE 1

ROTATING
DISC PROCESS


BIO-DISC PROCESS
SECONDARY CLARIFIER
DISINFECTION
PRIMARY EFFLUENT
EFFLUENT
TWO OR MORE STAGES OF SECONDARY BIOLOGICAL ROTATING DISCS... KNOWN UNDER AUTOTROL CORP. TRADEMARK AS BIO-DISC PROCESS
SETTLES OUT SLOUGHED BACTERIAL GROWTH
SECONDARY SLUDGE
SLUDGE DIGESTER
SUPERNATANT
PRIMARY SLUDGE
SOLIDS DISPOSAL

APPLICATION TO COMBINED SEWER TREATMENT

Studies have shown that peak loads of biodegradable pollutants can be absorbed and stored in the available biological mass on the RBC discs. As the hydraulic load increases, the built-in buffer capacity of the system is capable of maintaining continued treatment efficiencies for peak loads for a relatively short duration. Greater sensitivity to these peak loading situations is accomplished by multi-staging of RBC discs in series.

Under mild rainfall storm conditions, it was expected that the biological slime population on the rotating disc surface would not be adversely affected by increased hydraulic flows. Further, it was expected that the absorptive qualities of the biomass could adequately reduce organic pollutants of the combined domestic and sewer wastewater.

SECTION III

PHASE I - PRELIMINARY DESIGN

TASK I - SITE SELECTION

The selection of the demonstration site was one of the most critical tasks of Phase I. Conferences were held with the City Engineer and the Sewer Engineering Department for the City of Milwaukee, Wisconsin, to establish potential sites for the demonstration effort. Those factors considered in the screening related functionally to: area traffic pattern, conditions of local sewers, and availability of a combined sewer system, size and character of the area, population and industrial density of the area, geographic rainfall and runoff profile, possible construction problems, and availability of the site. Five Milwaukee sites were selected for more detailed investigation.

From the determinations made on these alternative sites, the South Eighth and West Montana Streets site was chosen as the most desirable location. This site had the following characteristics:

1. The availability of a drop manhole, which allowed for flexibility in the hydraulic design of the demonstration facility.
2. Sufficient drainage to supply the required dry and wet weather flows to the demonstration plant.
3. An unoccupied light industrial area adjacent to the site, which would be compatible for the construction of a demonstration plant.
4. A plotted street, which was not in use and could be used for construction purposes.

The aerial view of Figure 2 shows the features of the area in relation to the selected demonstration site. A panoramic view of the site area is shown in Figure 3. The North view shows the unoccupied industrial area, while the South view provides an indication of the type of residences that contribute sewage to the demonstration site. Tabulated in Table I are the estimated residential and population equivalents of the area. Actual house count of the 28.85-acre residential area showed a population equivalent of 1,040 persons, or 36 persons per acre. Several large schools and small individual concerns lie within the demonstration basin.

As diagrammed in Figure 4, the dry weather flow is carried away via a 30-inch diameter combined sewer in South Sixth Street. The 84-inch diameter combined outfall enters a junction chamber at West Cleveland Avenue, from which combined storm waste can be diverted into the Kinnickinnic River.

Hydraulic determinations (See Appendix C) at the site indicate a dry weather flow of 1,420 gallons per hour in the sewer outfall system.

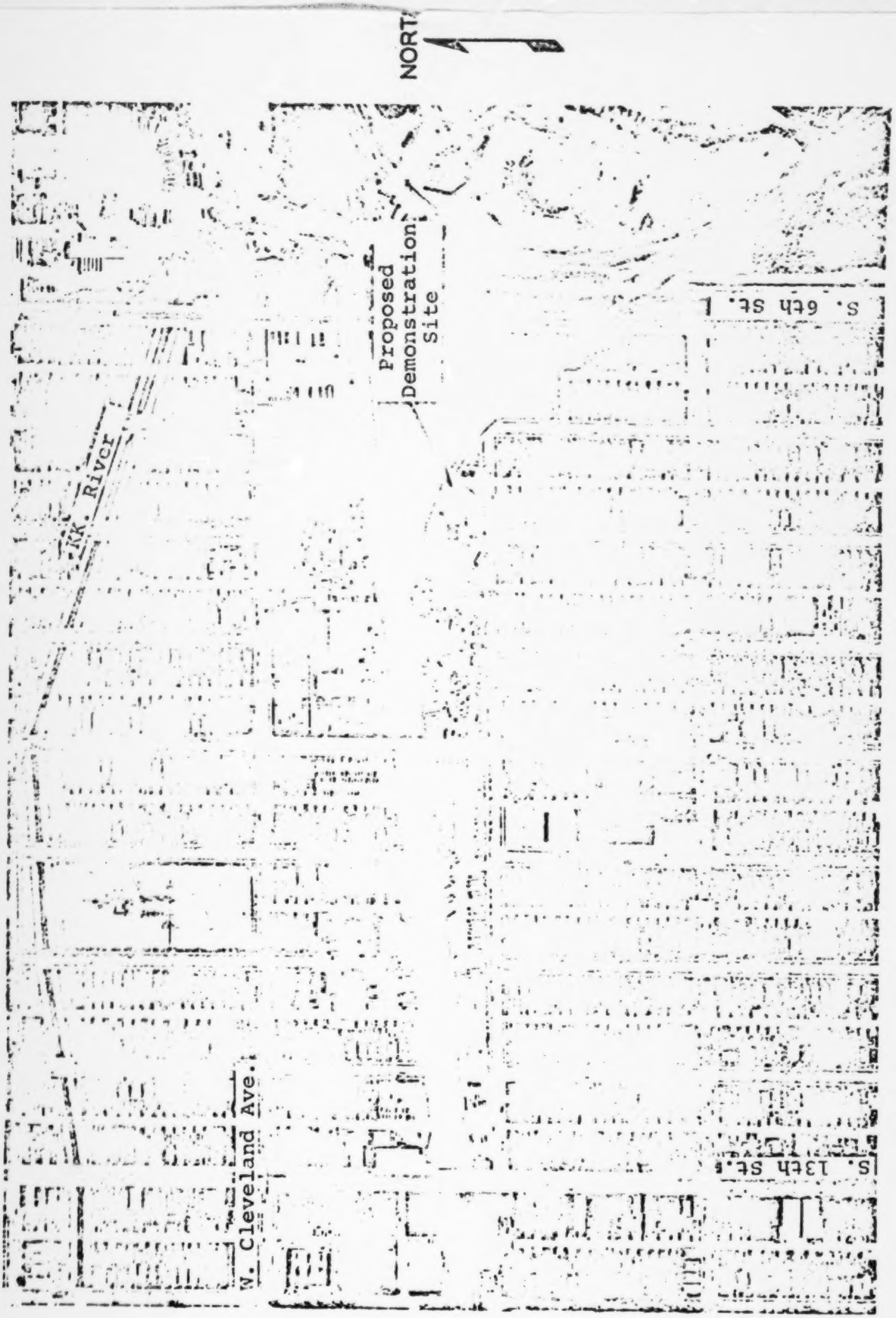

NORT
Proposed Demonstration Site
S. 6th St.
RR. River
W. Cleveland Ave.
S. 13th St.

FIGURE 2

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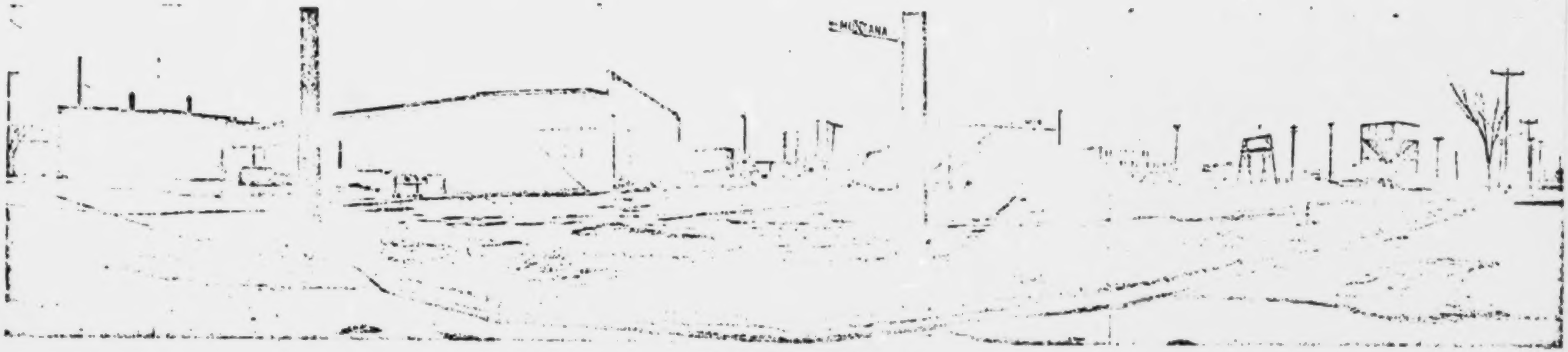
FIGURE 3

PANORAMIC VIEW OF PROPOSED DEMONSTRATION SITE

So. 8TH. ST. & W. MONTANA ST.

SOUTH VIEW



NORTH VIEW

TABLE 1

ESTIMATED POPULATION EQUIVALENT OF DEMONSTRATION AREA

Type of Unit	Population Equivalent
92 Single Family	368
49 Duplex	392
450 Student and Faculty	90
2 Tavern	20
	870

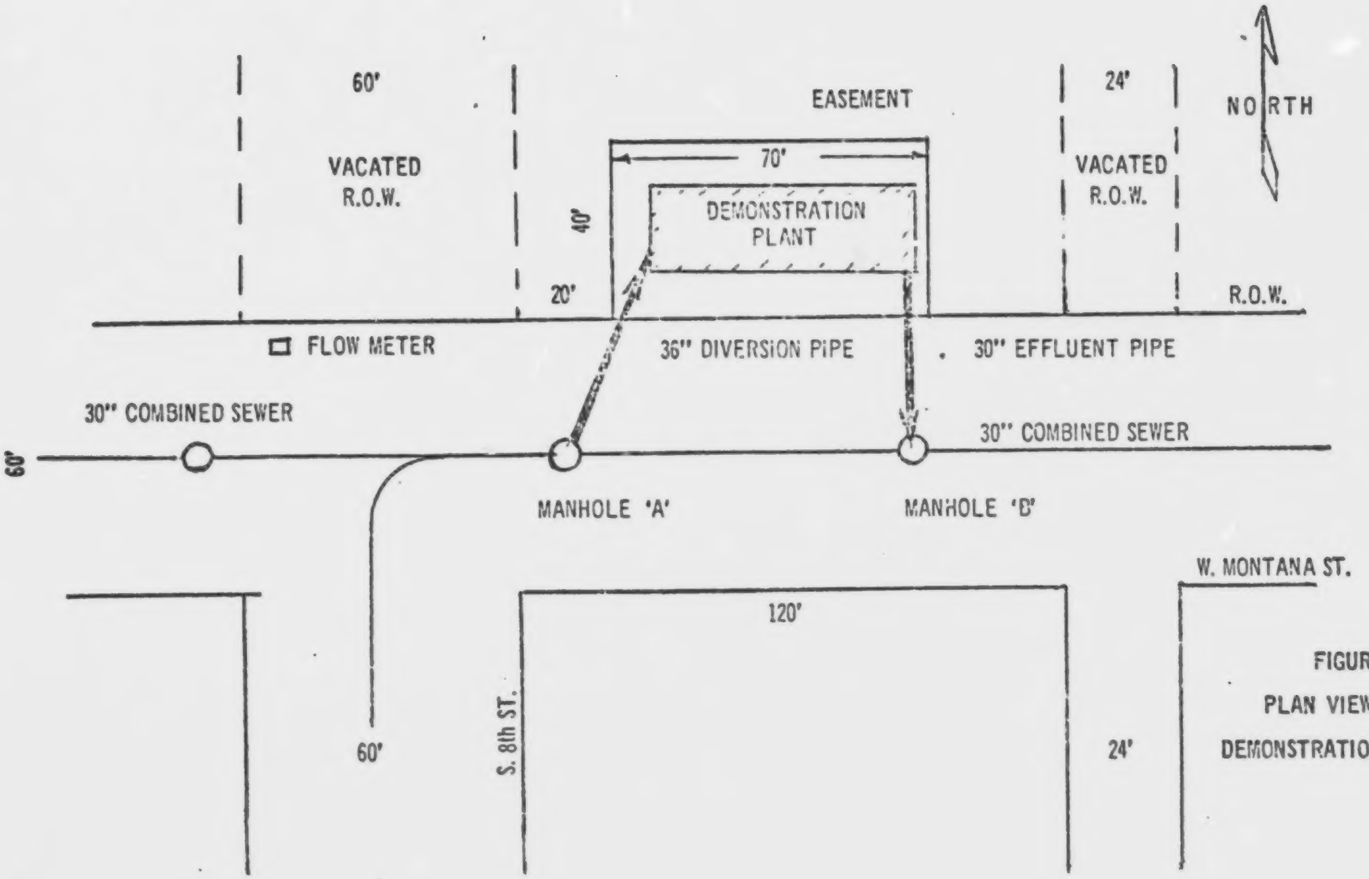

60'
VACATED
R.O.W.
EASEMENT
70'
DEMONSTRATION
PLANT
40'
20'
24'
VACATED
R.O.W.
NORTH
R.O.W.
☐ FLOW METER
36" DIVERSION PIPE
30" EFFLUENT PIPE
30" COMBINED SEWER
60'
30" COMBINED SEWER
MANHOLE 'A'
MANHOLE 'B'
W. MONTANA ST.
120'
60'
S. 8th ST.
24'

FIGURE 4

PLAN VIEW OF RBC

DEMONSTRATION PLANT SITE

Initial design for the proposed demonstration plant commenced with the calculation and measurements of the flow in the existing 30-inch diameter combined sewer in West Montana Street. A total of 34.91 acres is tributary to the manhole at the east side of South Eighth and West Montana Streets, which would be adjacent to the inlet structure of the proposed demonstration plant. Of the total tributary, 28.85 acres is residential, while the remaining 6.06 acres is light industry. A runoff coefficient of 0.50 (that portion of the rainfall which actually reaches the sewer system) was used for the entire drainage area.

The calculated capacity of the existing combined sewer in West Montana Street was based on Chezy's formula with Kutter's Coefficient (See Appendix B) assuming:

1. A 30-inch diameter concrete pipe with a slope of 1.25 percent.
2. A Kutter roughness coefficient of 0.013.
3. Flowing of 0.8 part full.

   The calculated capacity was 45 cfs with a velocity of 10.5 fps.

TASK II - SIMULATED RAINFALL TESTING

THE BENCH-SCALE RBC

The bench-scale RBC system (Figure 5) consisted of ten rows of 32 discs each. The discs were one foot in diameter and spaced at one-half inch, center to center. Rotational speed of the discs was maintained by a hydraulic drive system (Figure 6), which allowed for independent speed adjustment and direction of rotation of each row of discs. Tankage of the RBC unit was approximately 12 feet long, 1.5 feet wide, and 1 foot high with an operating capacity of approximately 60 gallons.

In simulated rainfall tests, concentrated synthetic sewage was prepared once or twice a week in a 500-gallon tank to a COD concentration of approximately 30,000 mg/l. As illustrated in the flow diagram of Figure 7, the concentrated sewage was then diluted in a mixing drum by tap water, at a constant temperature, to 500 mg/l COD. The required rate of dilution water was fed by a hydraulic valve controlled by a level controller in the mixing drum. Sewage flow was monitored through a rotometer at controlled rates to the RBC system.

For continuous or simulated dry weather flow conditions, RBC effluent was allowed to flow over a weir and to the drain by gravity. In this manner, a constant discharge rate was maintained for each test run.

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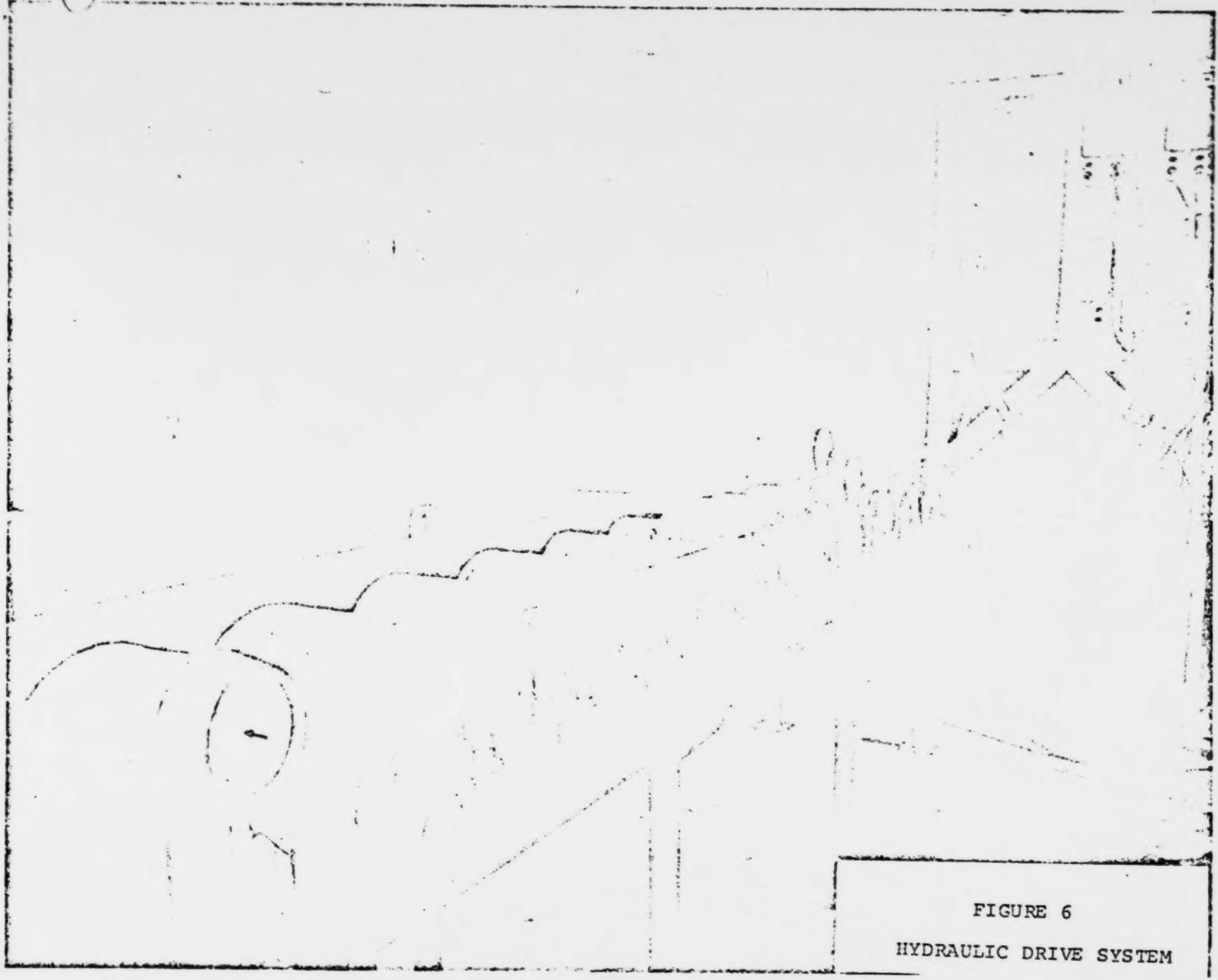
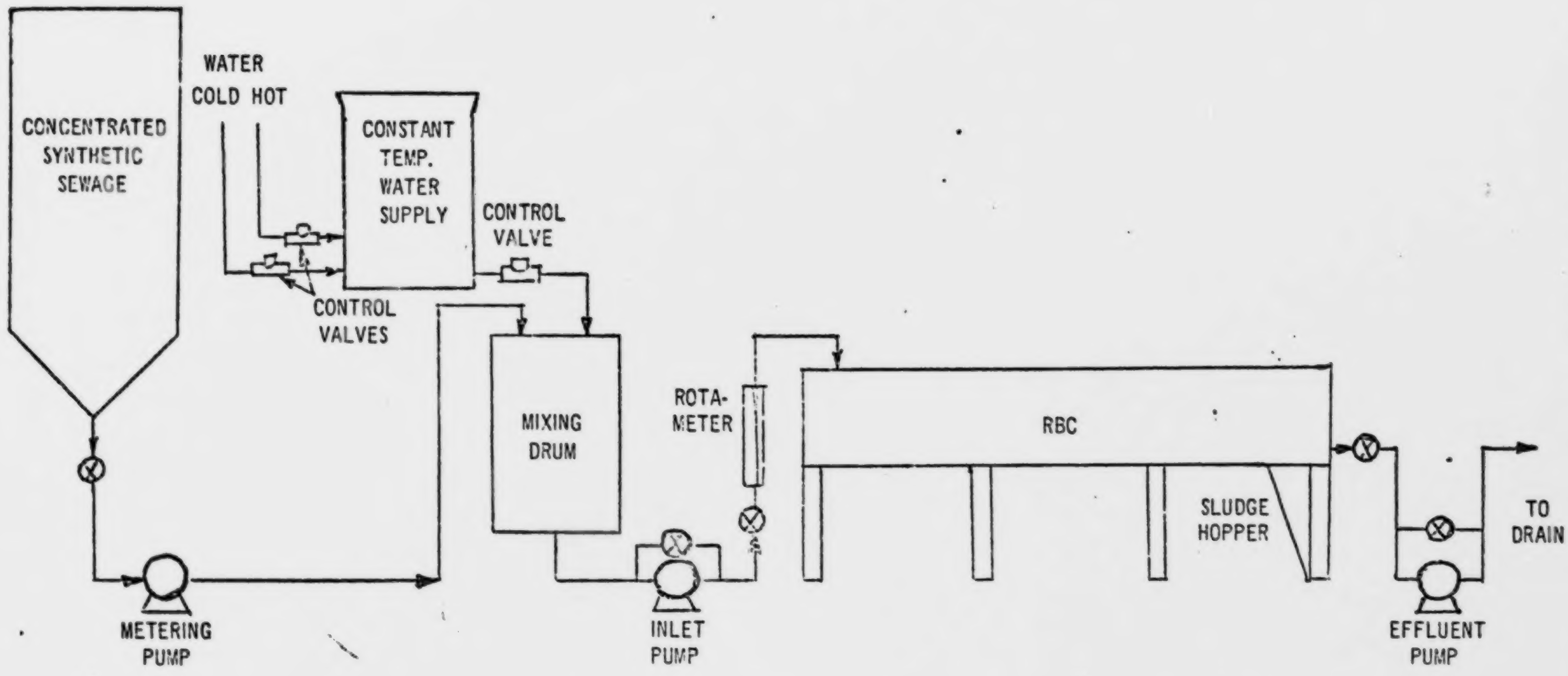


FIGURE 6

HYDRAULIC DRIVE SYSTEM

FIGURE 7

FLOW DIAGRAM FOR RBC AND SYNTHETIC SEWAGE SUPPLY SYSTEM


CONCENTRATED SYNTHETIC SEWAGE
WATER
COLD HOT
CONTROL VALVES
CONSTANT TEMP. WATER SUPPLY
CONTROL VALVE
MIXING DRUM
METERING PUMP
INLET PUMP
ROTA-METER
RBC
SLUDGE HOPPER
EFFLUENT PUMP
TO DRAIN

To simulate sudden or batch loading, a timer was used to control the feed rate of the sewage in cycles of 1 to 3 hours. In the simulated overflow tests, the timer turned on both the sewage metering and inlet pumps for one-half of the cycle time. For the second half of the cycle, nothing flowed in or out of the RBC system except in the last two minutes, at which time the outlet pump turned on to empty the RBC.

During the simulated rainfall test program, these bottom configurations (Figure 8) were evaluated:

1. Plain bottom, without obstructions.
2. Flat vertical baffles between rows of discs.
3. Contoured inserts under and between rows of discs.
4. Augered bottom used with the contoured inserts to remove grit and settled material.

A hopper was provided prior to the RBC when limited pretreatment was used. Data from these tests were used to determine if the auger system aided in removing sloughed biomass from the tank and if the auger exerted other effects on the overall performance of the RBC system.

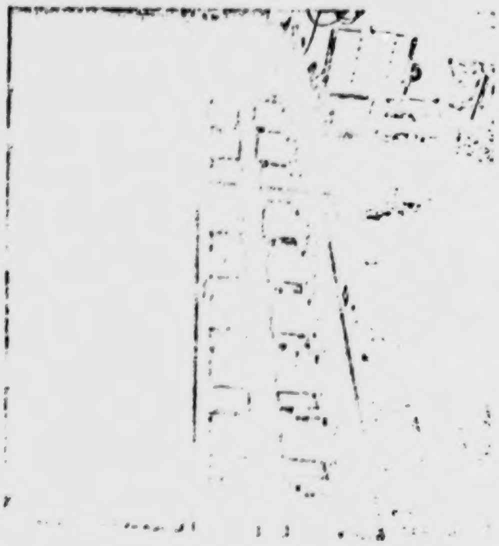
SAMPLING

All analytical tests were performed as outlined in Standard Methods, 12th Edition, with two exceptions. Suspended solids filtrations were performed with glass fiber mats, rather than asbestos, to assure mat uniformity and to save analysis time. Dissolved oxygen concentration was measured with a galvanic cell oxygen analyzer, rather than the Winkler Method.

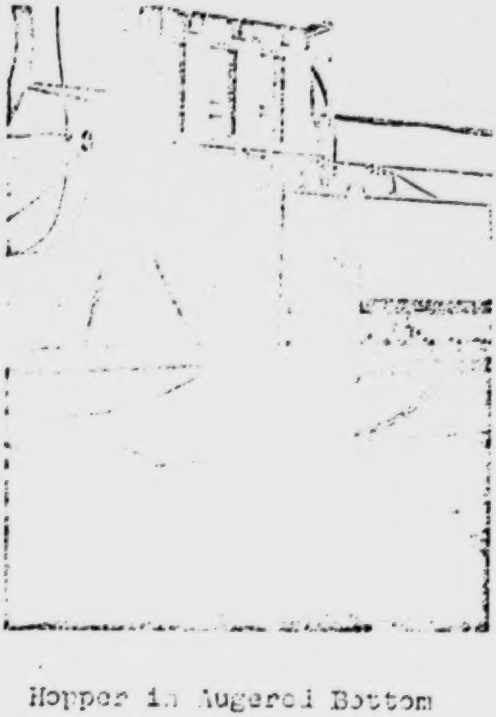
FIGURE 8

BOTTOM CONFIGURATIONS

Augered Bottom



Contoured Bottom



Hopper in Augered Bottom

Since the RBC system was operated under constant conditions, determinations were made on grab, rather than composite samples.

Secondary clarification effects of the effluent were evaluated on 30-minute, settled effluent samples. Completely mixed effluent samples were obtained by strong agitation of unsettled effluent in a commercial blender for thirty seconds. In the blending, the size of the biological floc was reduced to a more uniform size, allowing for greater ease of oxidation in the BOD and COD tests.

TEST RESULTS

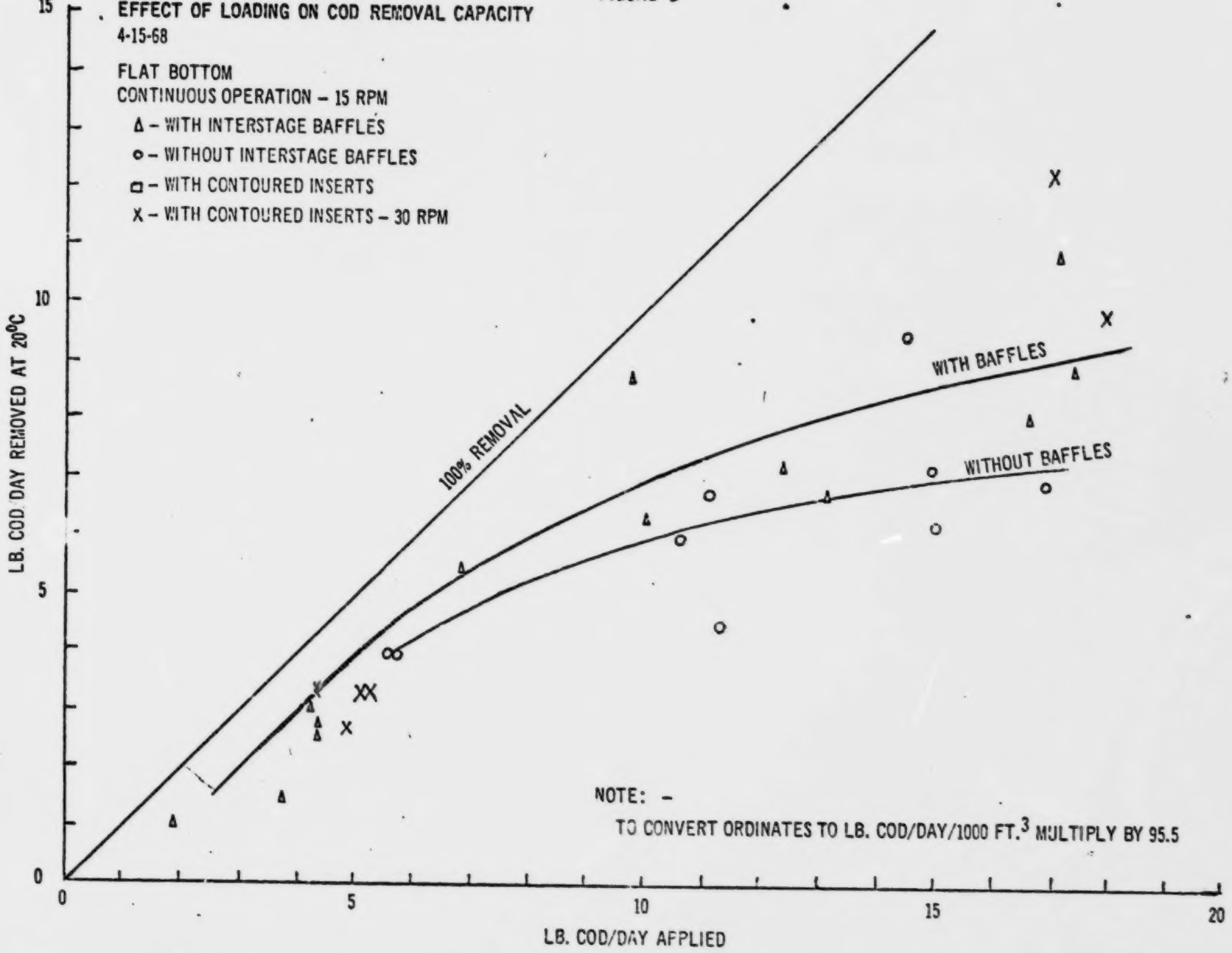
CONTINUOUS OPERATIONS

The results of organic removal under continuous operation are tabulated in Tables D-4 through D-6 of Appendix D. Figure 9 shows RBC performance under continuous operation with the flat-bottom tank configuration.

Within the restraints of the tests, 70% COD and BOD reductions were achieved for loadings up to 10 lbs. COD/day (6.6 lbs. BOD/day).

Although the data points in Figure 9 at high loading were somewhat scattered, the performance with baffles was better than without. As further indicated by the plotted data, test points using contoured inserts very nearly coincided with those using baffles. In these instances, the influence of bottom tank configuration was felt to be insignificant. As shown in Figure 10, a beneficial effect was gained when operating at a disc speed of 30 rpm rather than 15 rpm for high COD loads, but not at low loads.

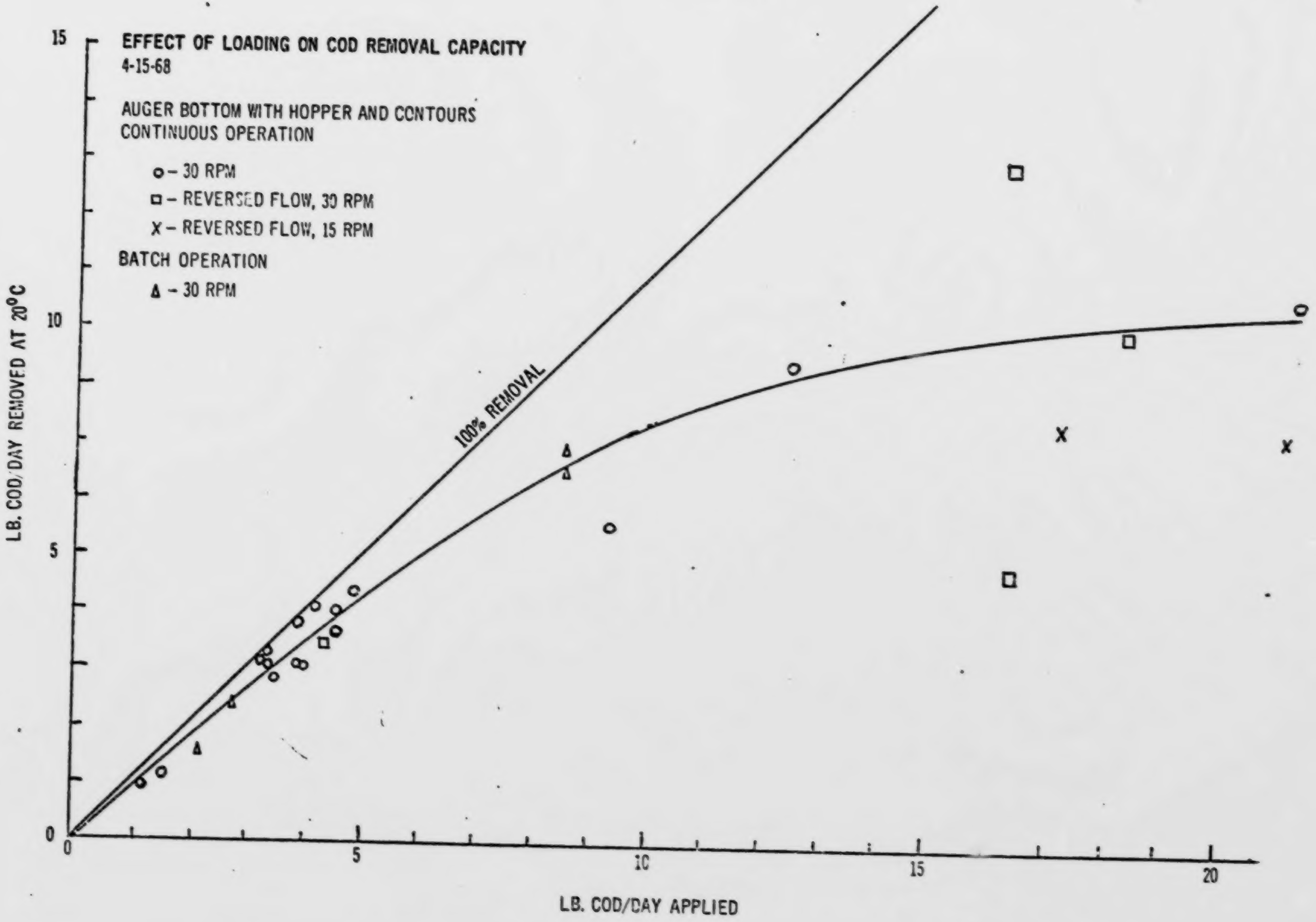
FIGURE 9



EFFECT OF LOADING ON COD REMOVAL CAPACITY
4-15-68

NOTE: –
TO CONVERT ORDINATES TO LB. COD/DAY/1000 FT.^{3} MULTIPLY BY 95.5

FIGURE 10



EFFECT OF LOADING ON COD REMOVAL CAPACITY
4-15-68

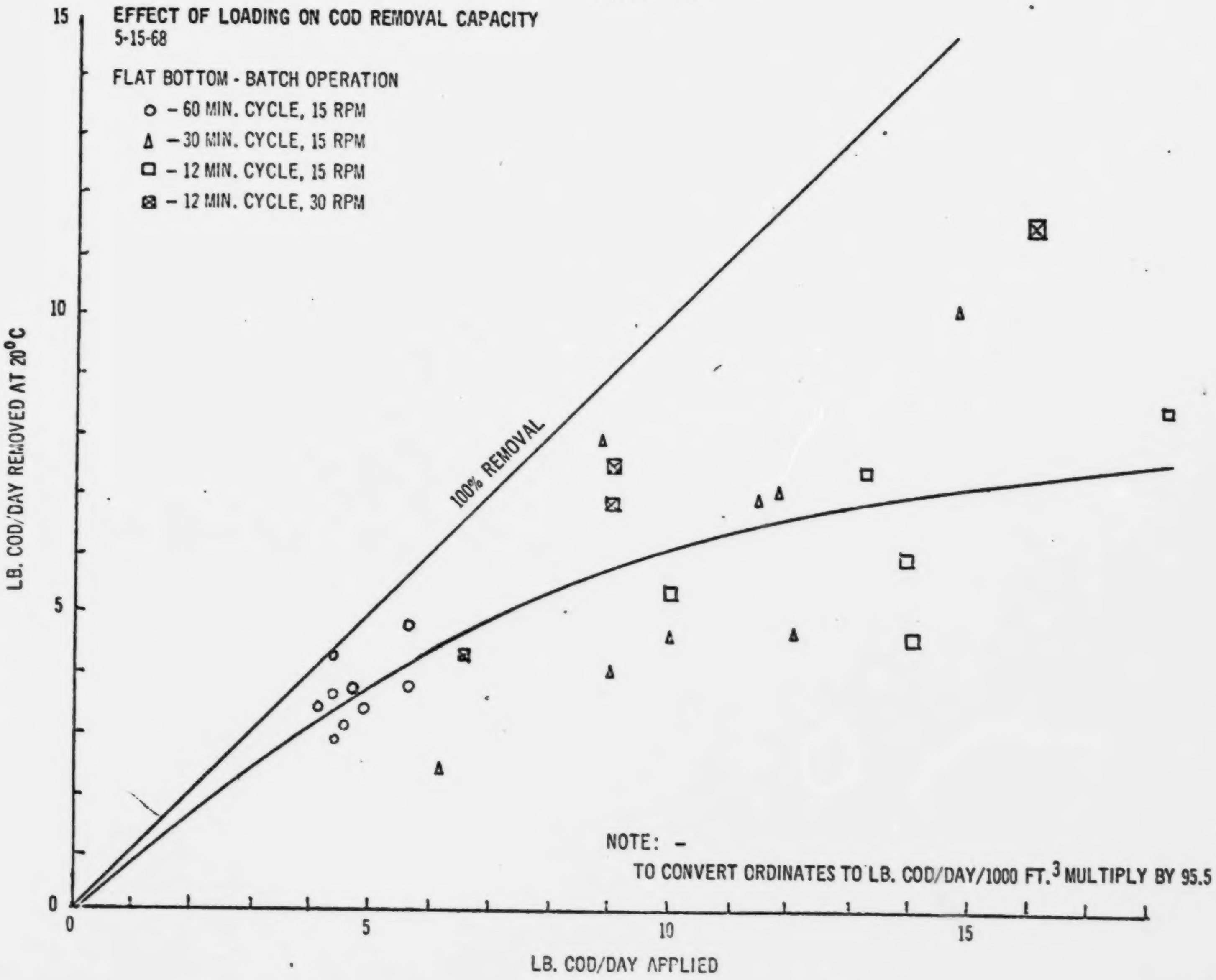
The augered bottom design also exhibited the advantage of 30 rpm over 15 rpm. COD and BOD reductions of 80% and 90% were achieved for loadings up to 5 lbs. COD/day (3.3 lbs. BOD/day). RBC efficiency was somewhat reduced to 70% COD and BOD for loadings increased to 10 lbs. COD/day and 6.6 lbs. BOD/day. Reversing the sewage flow through the RBC, having the hopper at the outlet end, did not demonstrate any apparent advantage for either mode of operation.

BATCH OPERATIONS

Batch tests were scheduled into the test program to determine if, in fact, this approach would provide substantially better performance than continuous operation. While a batch RBC process would complicate any system design or operation of the demonstration plant, it would have the advantage of providing a flushing action to the downstream sewer. Test results for batch operation with the augered bottom are included in Figure 10. These data points fall along the performance curve for continuous operation, indicating no real advantage to either process. Likewise, the data of Figure 11 for the flat bottom configuration without baffles also coincided with the continuous operation curve without baffles. Again, no advantage was shown using either method of operation. Neither method had an advantage over the others.

Use of settled effluent samples indicated the potential reduction in organic loading on any main treatment plant employing primary settling of its raw sewage.

FIGURE 11



EFFECT OF LOADING ON COD REMOVAL CAPACITY
5-15-68

NOTE: –
TO CONVERT ORDINATES TO LB. COD/DAY/1000 FT.^{3} MULTIPLY BY 95.5

BLENDED EFFLUENTS

COD and BOD reduction on blended effluent samples were tested to evaluate the probable effects of an in-line RBC system which might empty directly into a sewer without separation of mixed liquor solids. Data derived also indicated the degree of conversion of organic loading to biological solids, since the difference of BOD and COD between settled and blended effluents is attributed to the settleable biological solids. Table 2 shows the relationship of blended to settled COD concentrations and percent reductions.

The concentration of settled effluent was on the average 66% that of blended effluent. The COD reduction for effluent was also 66% that for settled effluent. RBC performance for settled and blended effluents is shown in Figure 12. Variation in data values was attributed to fluctuating solid levels of the samples.

SOLIDS PRODUCTION

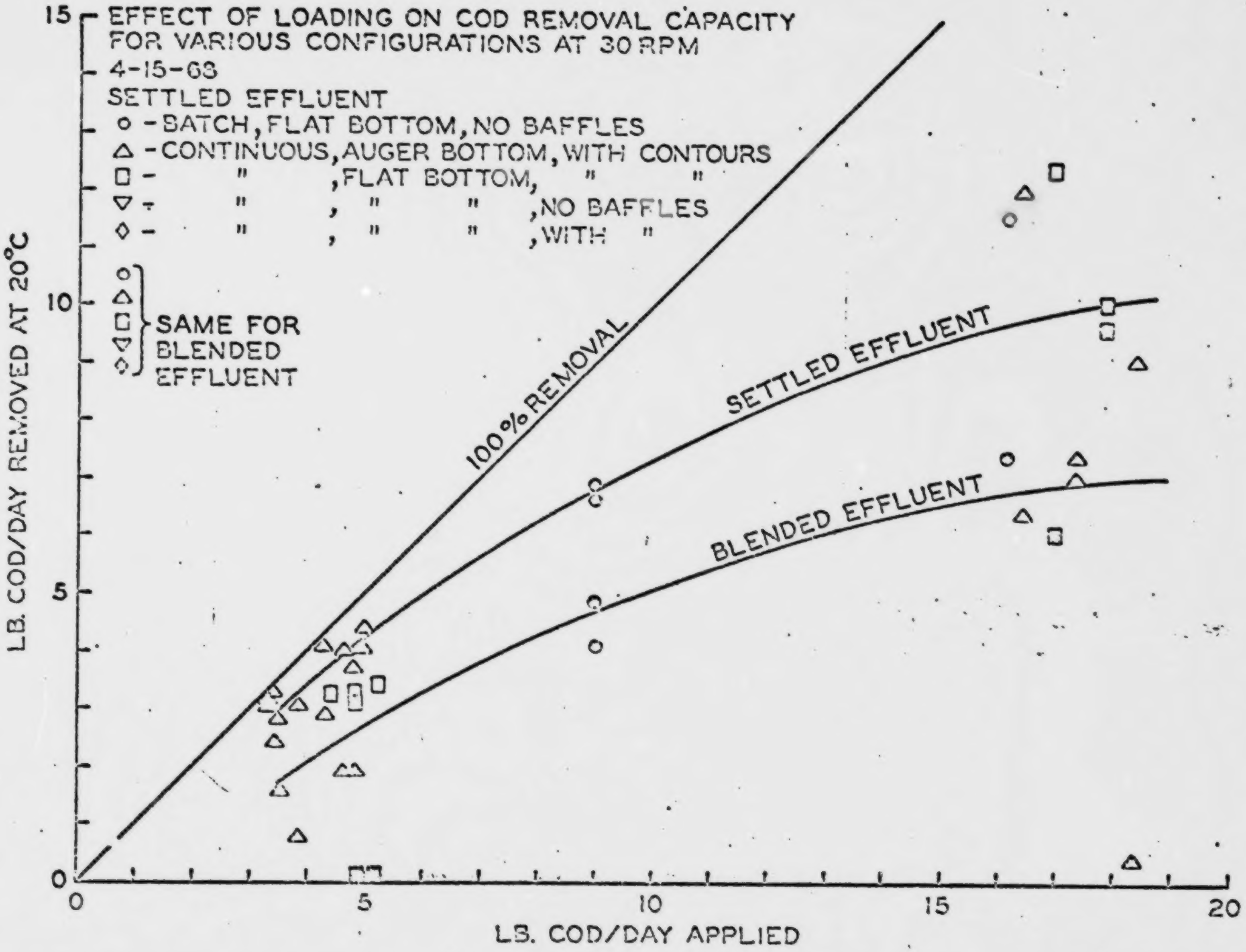
Included in Table 3 are the average solids production values of the test runs. These values had a large standard deviation value as a result of the gradual sloughing of biomass from the disc into the mixed liquor. Varying solids level also accounted for the diversity in COD values for blended effluent. Examination of total suspended solids data, with and without the augered bottom, indicated the following:

TABLE 2

SUMMARY OF AVERAGE VALUES FOR VARIOUS RBC CHARACTERISTICS

Measurement	Number of Determinations	Average	Standard Deviation
Ratio of BOD_5 to COD			
Inlet Sewage	15	.656	.111
Stage 6 Settled	7	.643	.093
Stage 6 Blended	4	.558	.097
Effluent Settled	15	.566	.103
Effluent Blended	14	.541	.111
Ratio of COD of Settled Effluent to Blended Effluent	43	.657	.293
Ratio of % COD Reduction of Blended Effluent to Settled Effluent	35	.664	.304
Solids Load on Receiving Body, lb/Day	37	3.17	2.11
Solids Removed from Effluent by Settling lb/Day	28	2.09	1.54
Suspended Solids Produced in Addition to those in Influent, lb/Day	33	1.97	1.43
lb Solids Settled from Effluent/lb COD Removed for Settled Effluent	27	.442	.301
lb Additional Solids Produced/lb COD Removed for Settled Effluent	30	.456	.343
Ratio of Volatile Suspended Solids to Total Suspended Solids			
Inlet	40	.705	.161
Effluent, Mixed	37	.764	.165
Effluent, Settled	35	.735	.166

FIGURE 12



EFFECT OF LOADING ON COD REMOVAL CAPACITY FOR VARIOUS CONFIGURATIONS AT 30 RPM

4-15-63

Table 3

Average Solids Production

Total Suspended Solids, lbs./day	Number of Determinations	Average	Standard Deviation
Without Auger	28	3.70	2.13
With Auger	9	1.81	1.12

Solids loading with the auger is shown to be nearly half that without the auger. The in-place auger did, in fact, demonstrate effective removal of sloughed solids under dry weather flow conditions. The effectiveness of the auger during wet weather flow conditions should have been reduced because of the high dilution factor, increased turbulence, and short retention time.

Further evaluation of the auger was done with actual combined domestic sewage at the Milwaukee Jones Island Sewage Plant. This work is discussed in Section V. It showed that an auger would be useful for removal of sludge in the demonstration plant.

RAIN SIMULATOR

Simulated rainfall data (Table D-3 , Appendix D) were acquired with the pilot RBC system under high hydraulic and organic loadings. To simulate rainfall flow events, the hydraulic flow rate was maintained between 500 to 1,000 gph. This range related to the critical 3 to 6 minute storm overflow period expected for the proposed demonstration plant. The synthetic sewage concentration was maintained near the 500 mg/l COD or estimated BOD concentration of 330 mg/l. Runoff from rain usually carries sufficient organic matter to maintain the wet weather sewage concentration near that for dry-weather sewage.

Figure 13 indicates the rate at which the RBC system returned to steady-state efficiencies following the simulated rain flows. Steady-state flow was established at 60 gph. At this hydraulic rate, waste residence time was approximately one hour in the RBC unit.

After simulated storm conditions, the transition back to steady-state operation occurred 1 to 2 hours once the upset condition ceased or was controlled. During the transition, pilot plant recovery was achieved about 20 minutes after residence time had increased to 15 minutes through the RBC system.

Figure 14 shows the increased organic removal capacity obtained during high flows. Data variation increased as loading increased, but the removal capacity of the RBC appeared to become asymptotic at about 18 lbs. COD/day. Comparative effects of residence time on COD removal during dry and wet weather flows are shown in Figure 15.

Although the RBC yielded decreasing percent BOD reduction for decreasing residence time, unit response to change in flow was rapid and predictable. At the same time, the data did not indicate any deleterious effects on the biomass, such as clogging or washing out, which are experienced at high flows by the trickling filter and activated sludge processes.

On two occasions, the RBC unit was operated with the discs completely submerged in the sewage for 3 to 4 hours. During this period, the mixed liquor D.O. remained at levels equal to or greater than 1.0 mg/l. Surface agitation caused by the

FIGURE 13

EFFECT OF SIMULATED RAINFALL ON COD REMOVAL EFFICIENCY

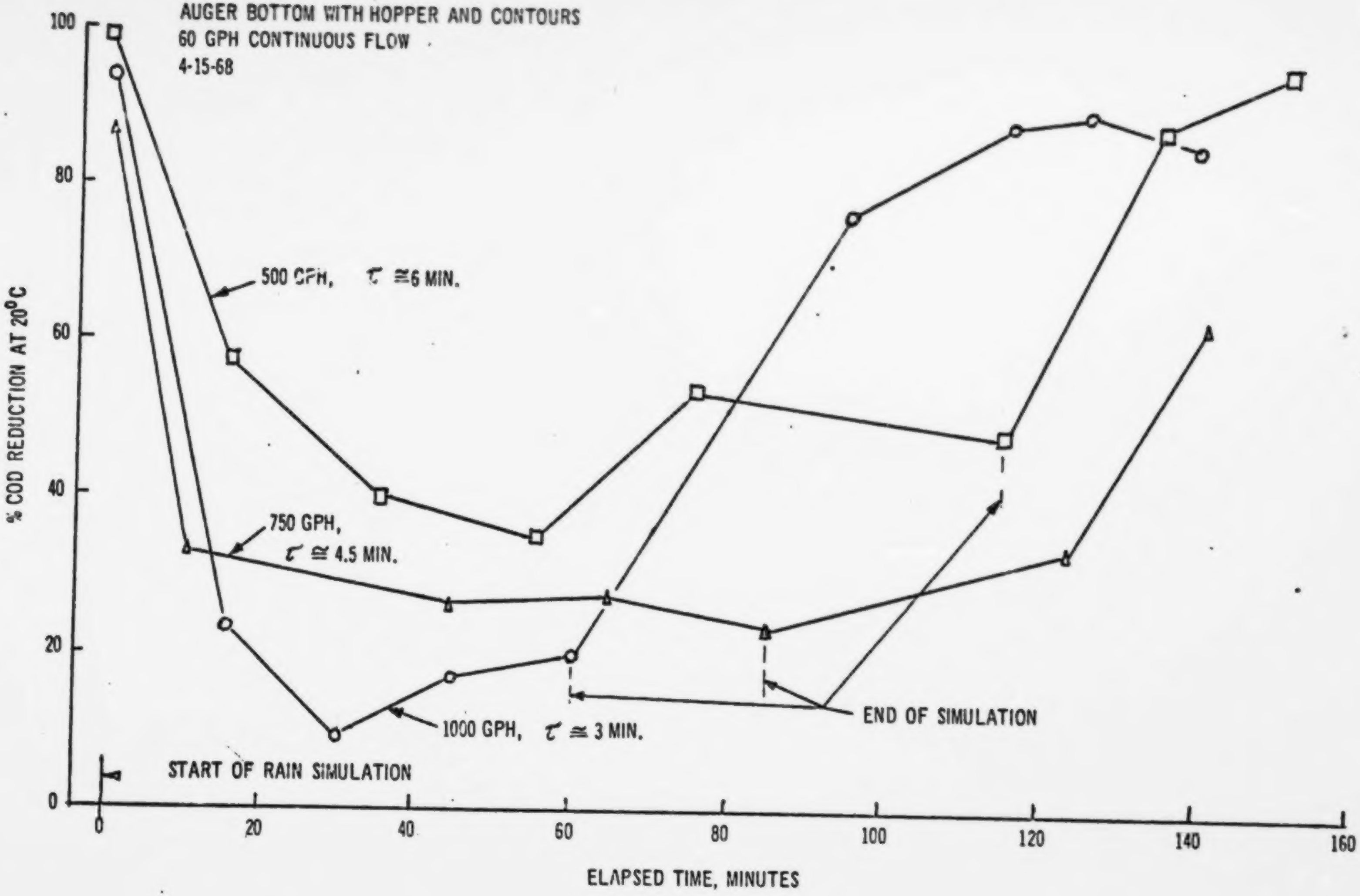


FIGURE 14

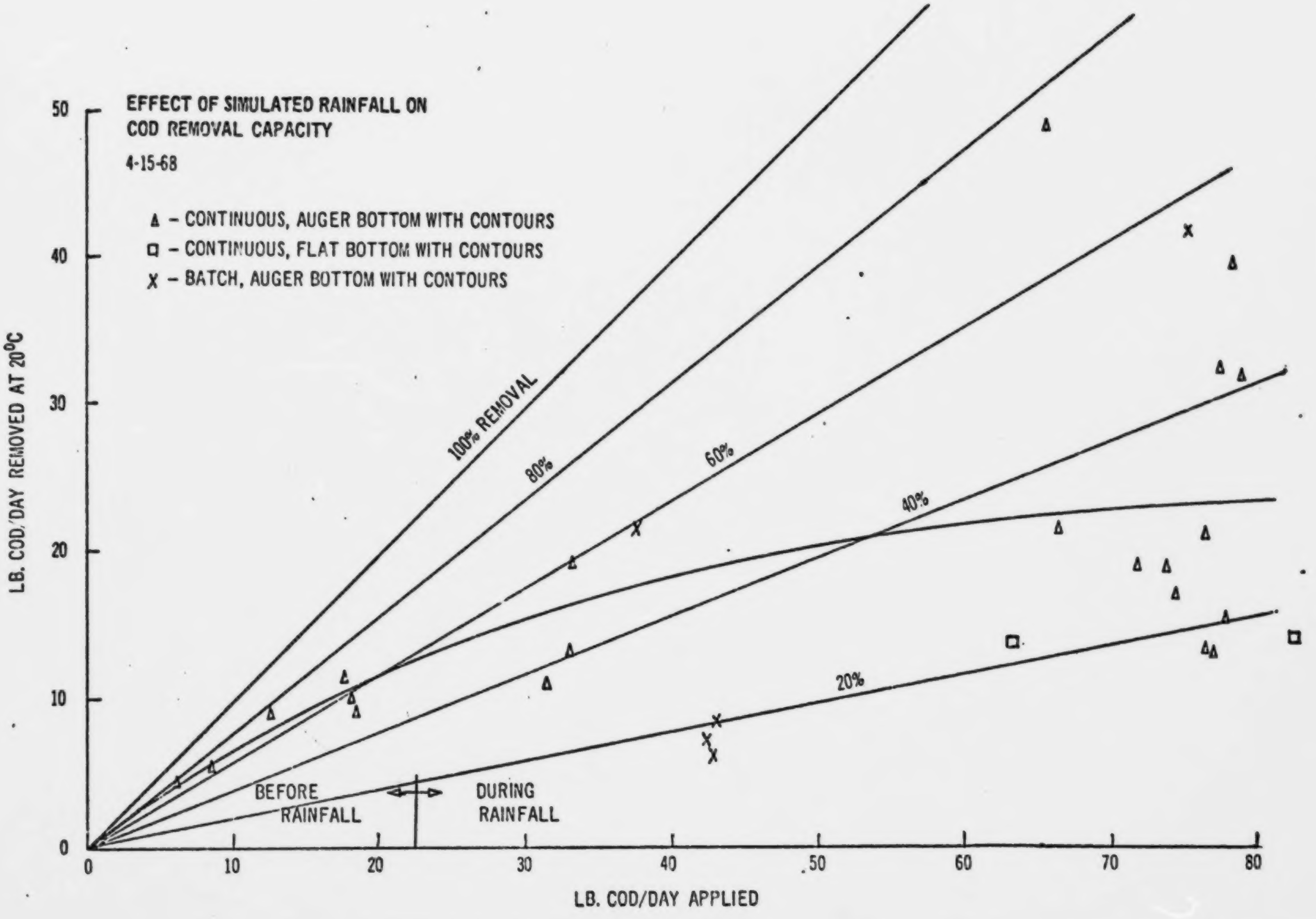
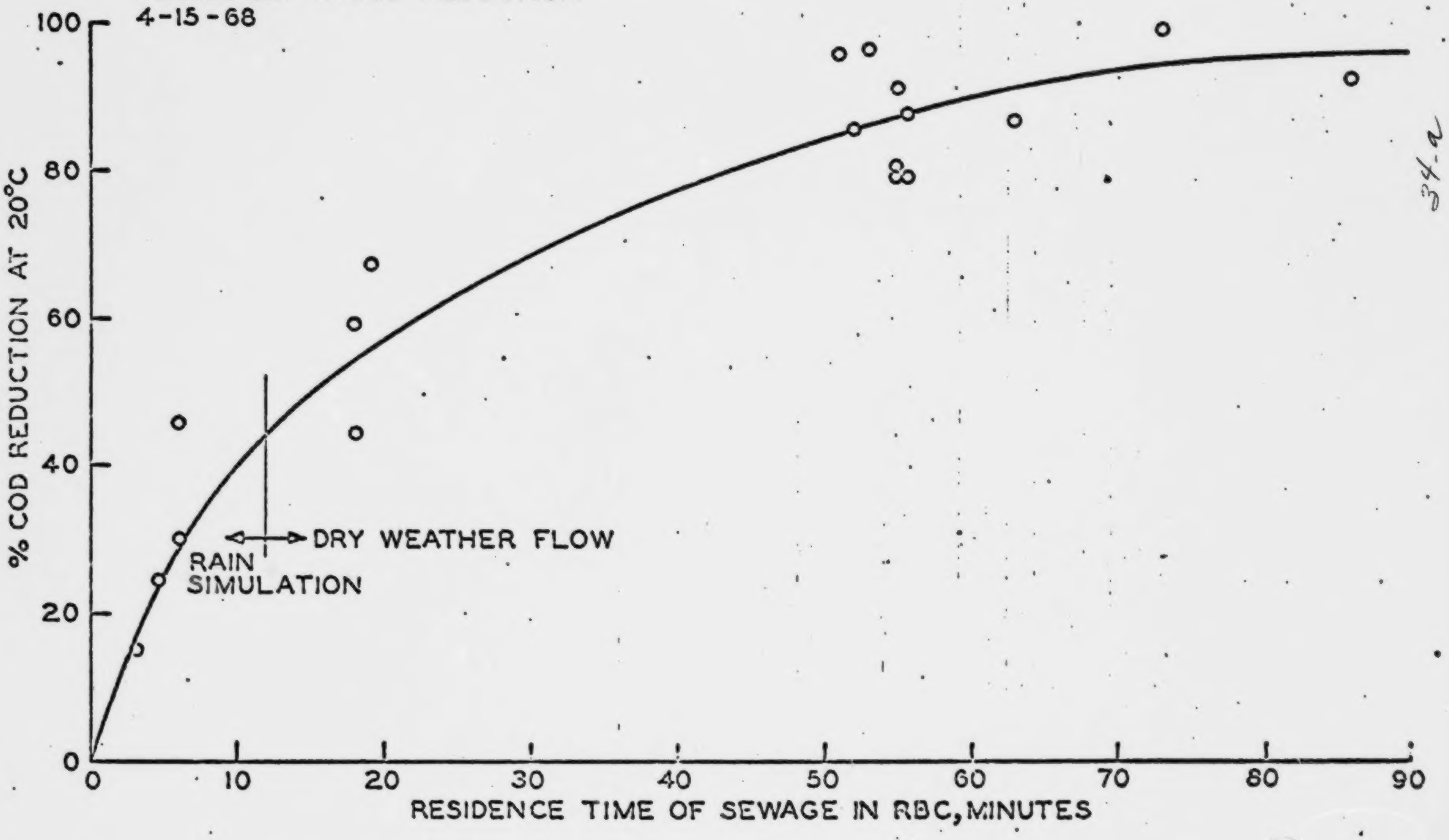

EFFECT OF SIMULATED RAINFALL ON
COD REMOVAL CAPACITY
4-15-68
Δ - CONTINUOUS, AUGER BOTTOM WITH CONTOURS
□ - CONTINUOUS, FLAT BOTTOM WITH CONTOURS
X - BATCH, AUGER BOTTOM WITH CONTOURS
100% REMOVAL
80%
60%
40%
20%
BEFORE RAINFALL
DURING RAINFALL
LB. COD/DAY REMOVED AT 20°C
LB. COD/DAY APPLIED
0
10
20
30
40
50
60
70
80

FIGURE 15
EFFECT OF WET AND DRY WEATHER
FLOWS ON % COD REDUCTION
4-15-68



submerged rotating discs at 15 rpm was adequately aerating the sewage. Organic removal efficiencies were not adversely affected during or following the period of total submergence with no loss of biomass.

In summary, the determinations made under dry-weather and simulated rain conditions demonstrated feasibility of the RBC process to handle combined storm waste. At the same time, results on settled effluent samples indicated the potential gain in providing downstream settling of the effluent prior to being discharged to any river tributary or outfall. In this regard, test results indicated 90% BOD and COD reduction on settled effluent, whereas only 60% was realized for unsettled samples at the dry weather flow of 50,000 gpd. At 20 times dry weather flow, the RBC process was still providing treatment at levels of 15% BOD and COD reductions in the critical 5-to 10-minute storm overflow period. Since the biological solids in the RBC effluent would provide further downstream treatment, the organic load could be expected to be reduced by more than that experienced in the pilot RBC unit.

SECTION IV

MUNICIPAL SEWAGE TREATMENT WITH THE RBC PILOT PLANT

GENERAL

Under contractual agreement with the FWPCA, extension of testing of the RBC pilot unit was scheduled to gain experience under actual field conditions on raw sewage. Moreover, the extended tests were planned to verify RBC results obtained with synthetic waste during Phase I and to substantiate the foreign literature results on a similar RBC unit in Europe (See also Appendix A). The site selected for testing was the Milwaukee Municipal Sewerage Plant on Jones Island in Milwaukee, Wisconsin.

Two independent variables, feed rate and disc rotational speed, were controlled. Primary clarification of the raw sewage was employed only in the later phase of this task. Secondary settling of RBC effluent was maintained throughout the project. By analysis of the mixed liquor, it was possible to ascertain the extent of biological treatment of the in-line RBC plant. As determined in this task effort, efficiency of the RBC was evaluated in terms of chemical oxygen demand, nitrogen, phosphorus, and suspended solids removal.

JONES ISLAND SYSTEM

A photograph of the RBC unit at Jones Island is shown in Figure 16. The flow diagram for the RBC unit at Jones Island is shown in Figure 17. Screened sewage was pumped to a primary clarifier from which it flowed to the RBC, to a secondary clarifier; and back to the sewage plant. During operation, sludge

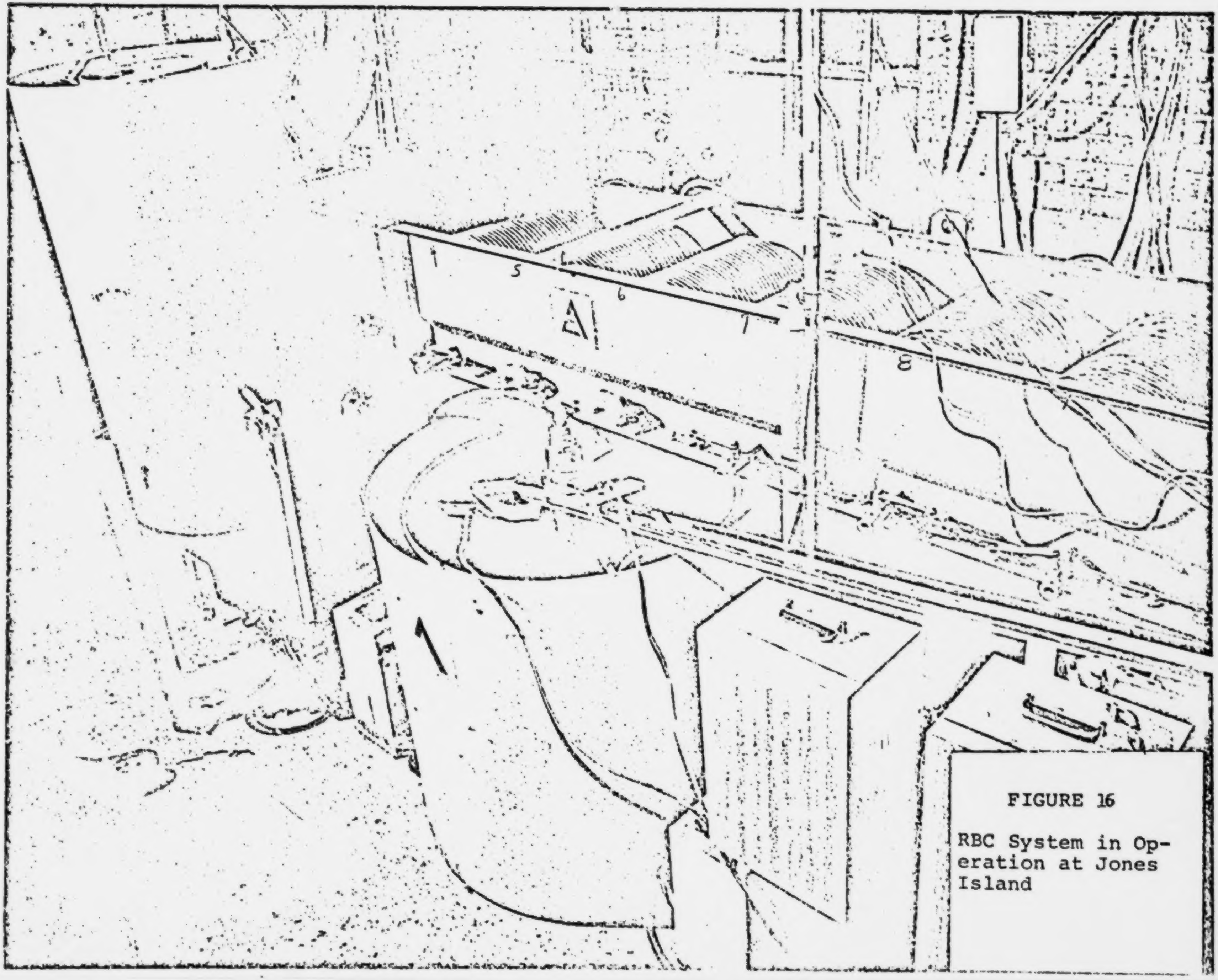


FIGURE 16

RBC System in Operation at Jones Island

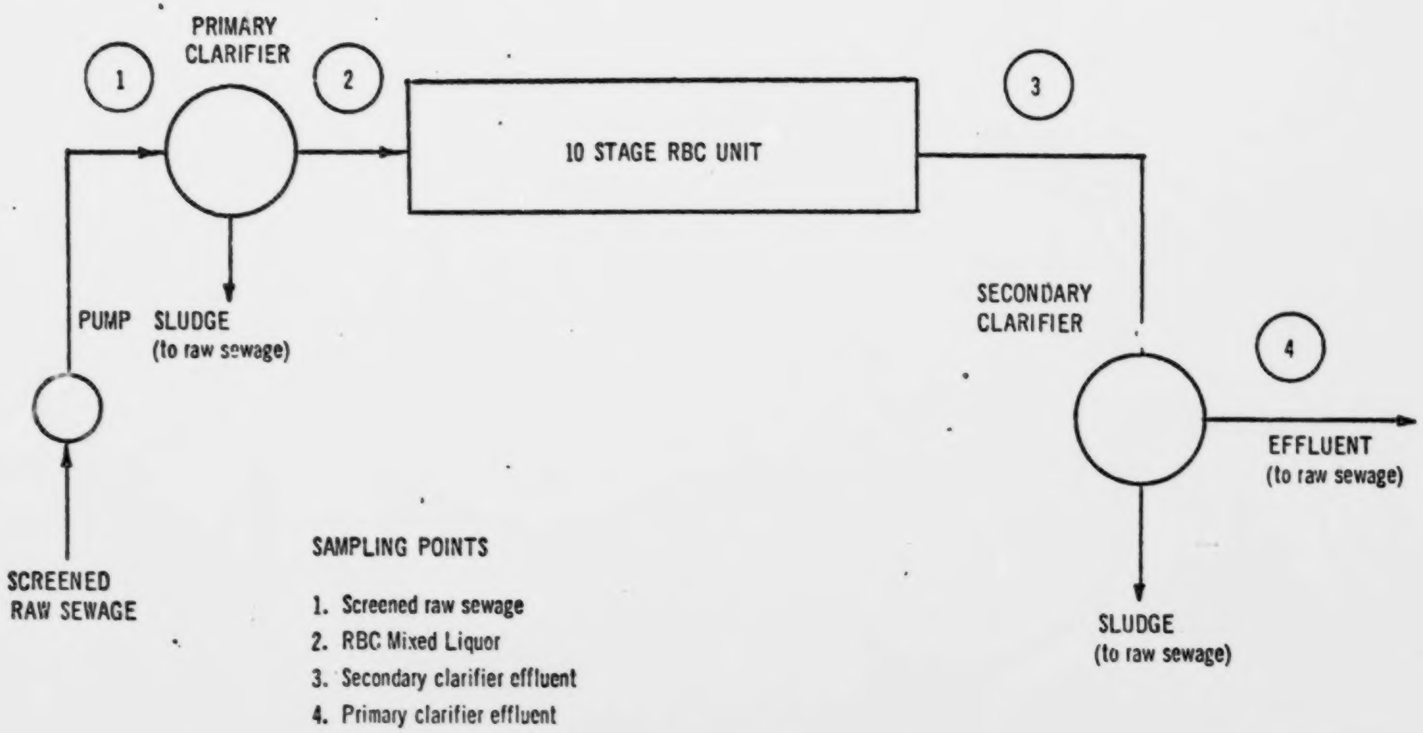

PRIMARY CLARIFIER
1
2
10 STAGE RBC UNIT
3
PUMP
SLUDGE (to raw sewage)
SECONDARY CLARIFIER
4
EFFLUENT (to raw sewage)
SCREENED RAW SEWAGE
SLUDGE (to raw sewage)
SAMPLING POINTS
1. Screened raw sewage
2. RBC Mixed Liquor
3. Secondary clarifier effluent
4. Primary clarifier effluent

FIGURE 17. RBC SYSTEM DIAGRAM

scum were removed from the primary clarifier daily. At low flows, the secondary clarifier sludge was also removed on a daily basis. At high flow rates, the secondary clarifier sludge was withdrawn more frequently.

Three Brailsford* samplers were installed to take samples at points 1, 3, and 4 (Figure 16). Twenty-four hourly samples were composited for most of the tests. The samples used for dissolved phosphorus, ortho-phosphate, ammonia, nitrite and nitrate were filtered through #4 Whatman* and .45 micron Millipore* filters and then composited. Unfiltered samples were used for COD, BOD, Kjeldahl nitrogen solids, and total phosphorus. Temperature, dissolved oxygen, and pH were monitored continuously.

The set-up for the meters and recorders is shown in (Figure 18). The analysis run on the samples and the frequency are listed in Table 4. All tests were run according to Standard Methods procedures, except for some modifications in suspended solids, total phosphorus, and turbidity.

OPERATIONS AND RESULTS

The data from this pilot plant operation are tabulated in Tables F-1 through F-8 of Appendix F. Table F-2 shows the physical characteristics of the sewage as well as pH. Percent

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*Mention of commercial products does not imply endorsement by the FWQA or by the contractor.

TABLE 4

ANALYSIS PERFORMED ON JONES ISLAND SYSTEM

	Frequency	Sampling Points
Temperature	Continuous	1, 2
pH	"	1, 2
Dissolved Oxygen	"	1, 2
Chemical Oxygen Demand	Daily	1, 2, 3, 4
Settleable Solids	"	1, 2, 3, 4
Total Suspended Solids	Weekly	1, 2, 3, 4
Volatile Suspended Solids	"	1, 2, 3, 4
Biochemical Oxygen Demand	"	1, 2, 3, 4
Total Phosphorus	"	1, 2, 3, 4
Dissolved Phosphorus	"	1, 2
Orthophosphate	"	1, 2
Kjeldahl Nitrogen	"	1, 2, 3, 4
Ammonia Nitrogen	"	1, 2
Nitrite Nitrogen	"	1, 2
Nitrate Nitrogen	"	1, 2
Turbidity	Daily	1, 2, 3, 4

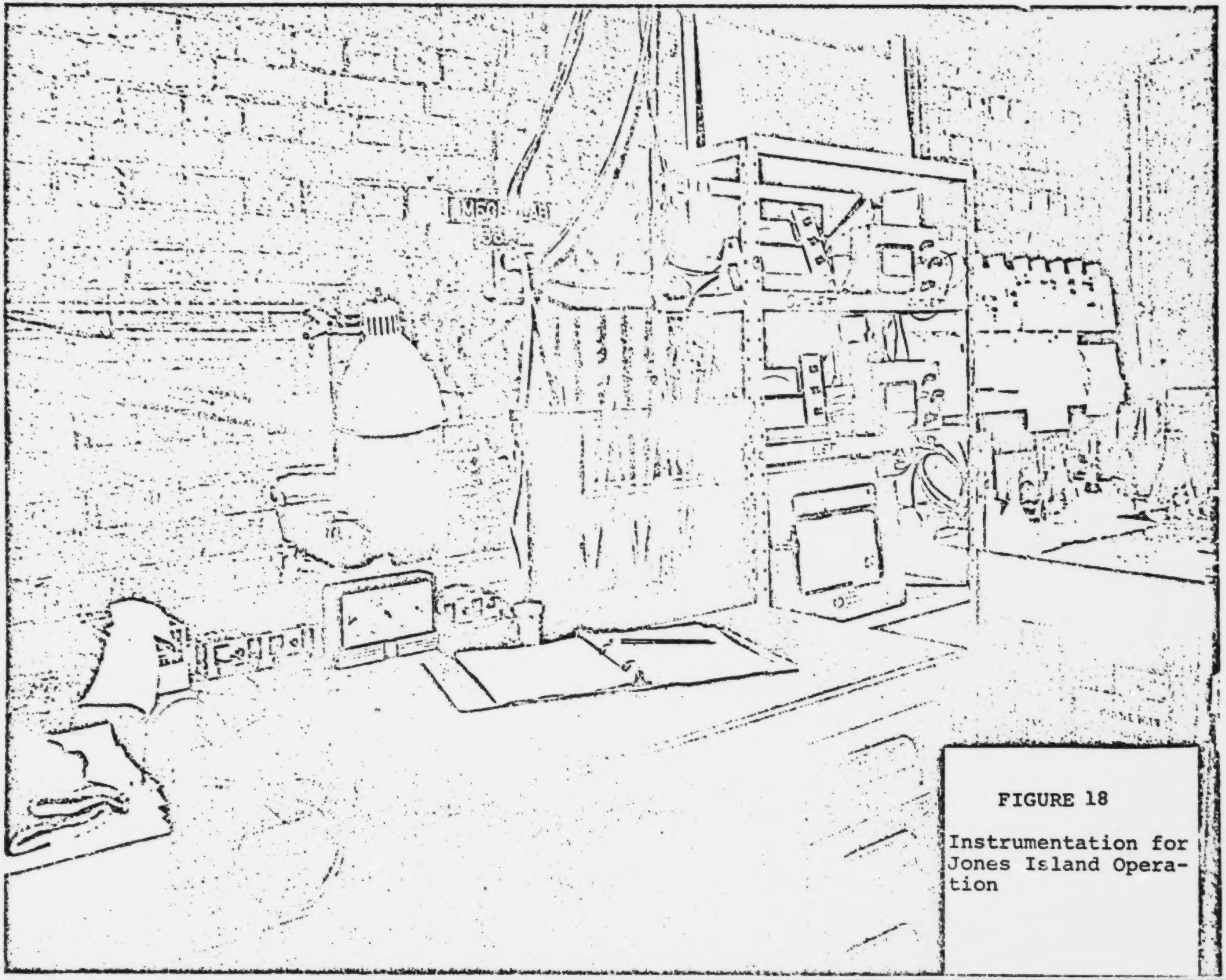


FIGURE 18

Instrumentation for Jones Island Operation removals were adjusted to 20°C for comparison purposes. The pH observations had a range of 6.4 to 8.6. The influent ratio of BOD to COD averaged 0.64 with a range of 0.47 to 0.85. The effluent ratio averaged 0.46, ranging from 0.19 to 0.91. The average of the BOD to COD ratio in the mixed liquor was 0.51, with a range of 0.31 to 0.87.

Table F-2 contains the oxygen parameter information. The analysis of solids, nitrogen, and phosphorus are shown in Tables F-4, F-5, and F-6 respectively.

ORGANIC REMOVAL EFFICIENCIES

Figures 19 and 20 show the RBC organic removal rates established at Jones Island. These data indicate that unit efficiency increased with increasing loads to some maximum level. Thereafter, the rate asymtotically leveled off between 28 to 32 lbs COD/day. Highest efficiencies were achieved at low applied loads and lowest for the higher applied loads. Figure 21 relates efficiencies as a function of residence time in the RBC system. Highest COD reduction rates were obtained between 35 and 40 minutes.

Figure 22 compares RBC efficiencies on synthetic waste (dairy Whey) and domestic sewage. Results on domestic sewage, in addition to verifying earlier results, also supplement a portion of the data curve which was not previously measured.

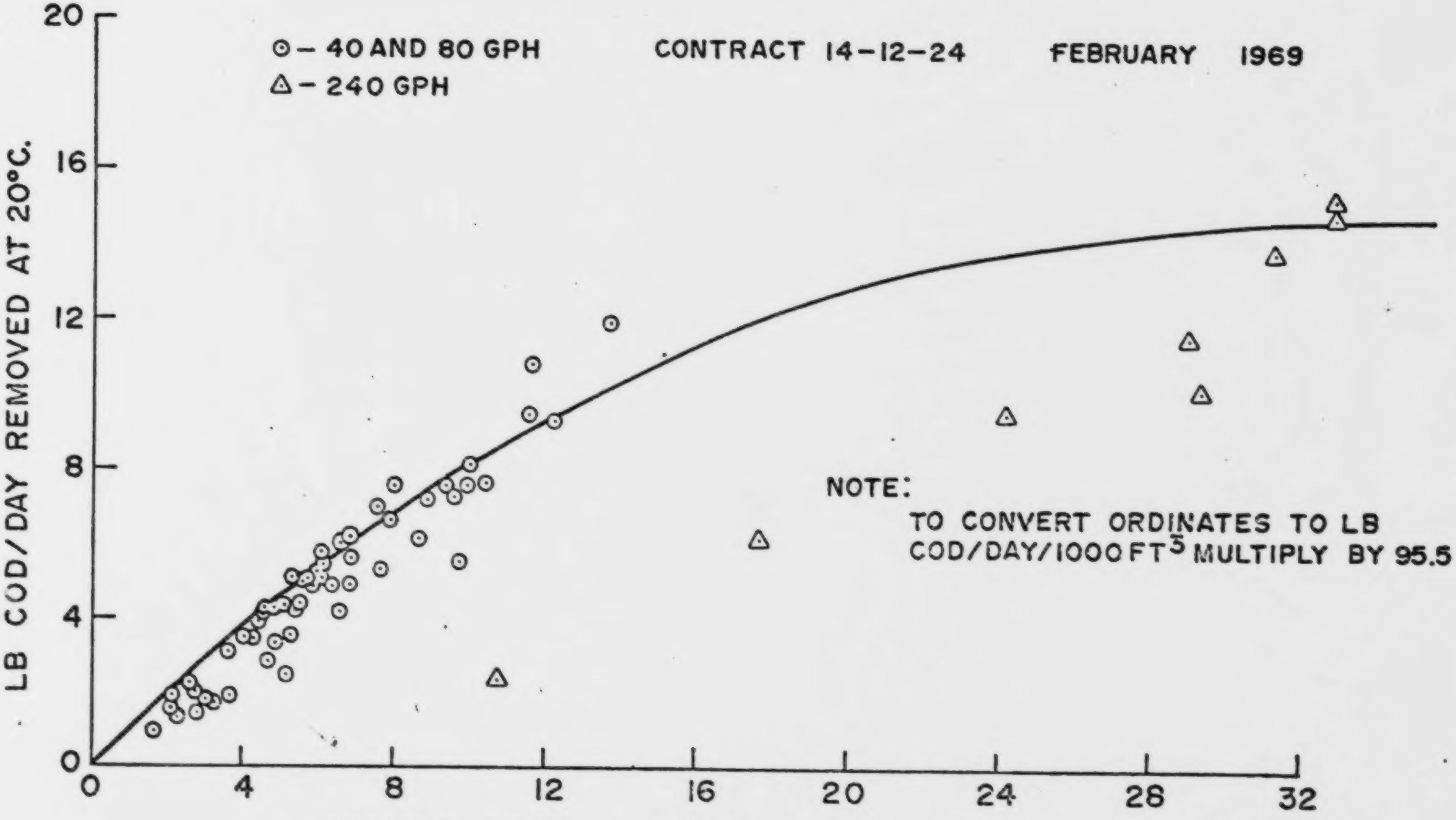
FIGURE 19

EFFECT OF LOADING ON COD

REMOVAL AT 20°C

(DRAFTING)

EFFECT OF LOADING ON COD REMOVAL AT 20°C.



NOTE:
TO CONVERT ORDINATES TO LB COD/DAY/1000 FT^3 MULTIPLY BY 95.5

FIGURE 19

FIGURE 20

EFFECT OF WASTE STRENGTH ON COD
REMOVAL AT 20°C
(DRAFTING)

EFFECT OF WASTE STRENGTH ON COD REMOVAL AT 20°C

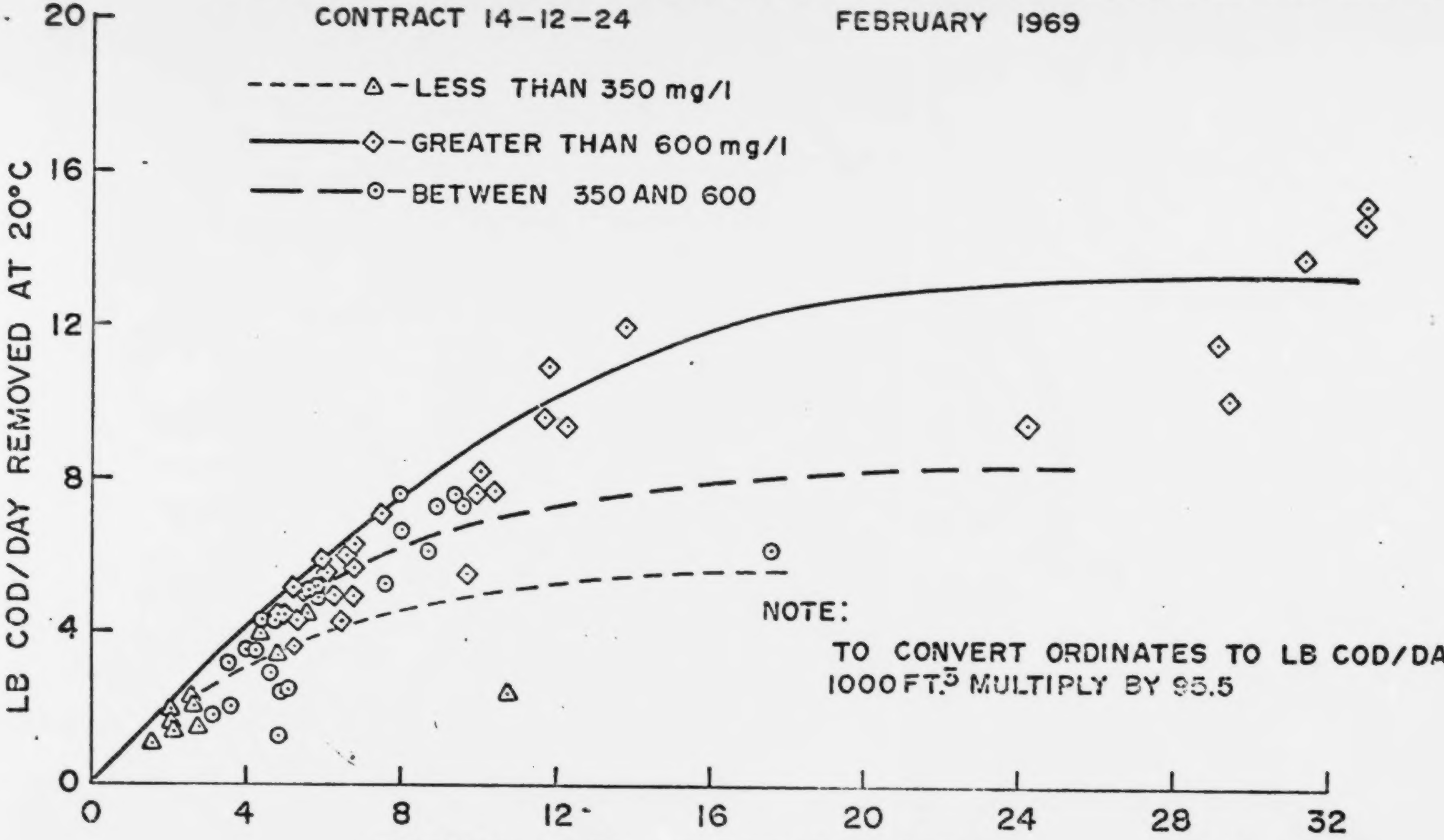


FIGURE 20

NO. 340-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

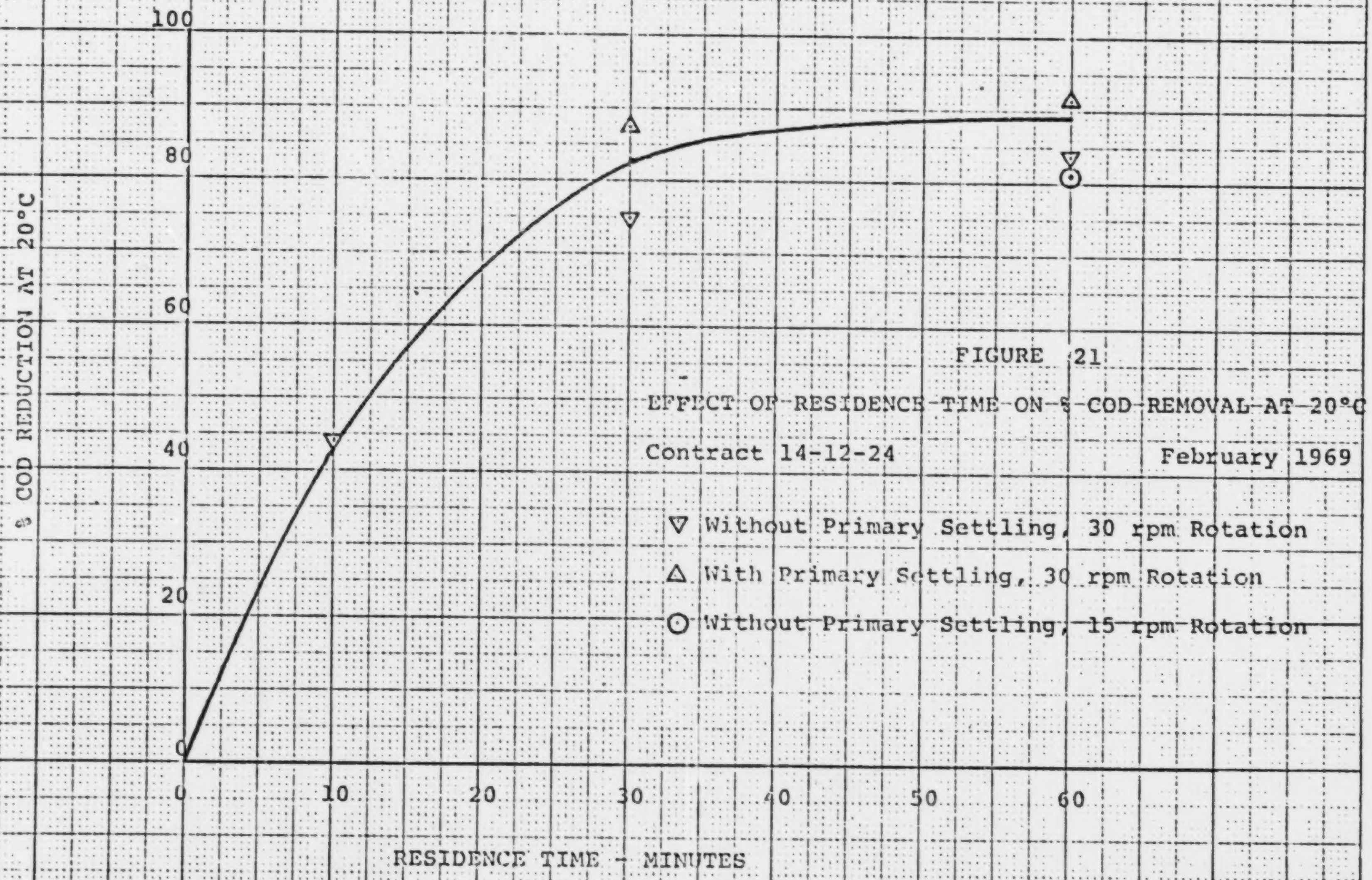


FIGURE 21

EFFECT OF RESIDENCE TIME ON % COD REMOVAL AT 20°C

Contract 14-12-24 February 1969

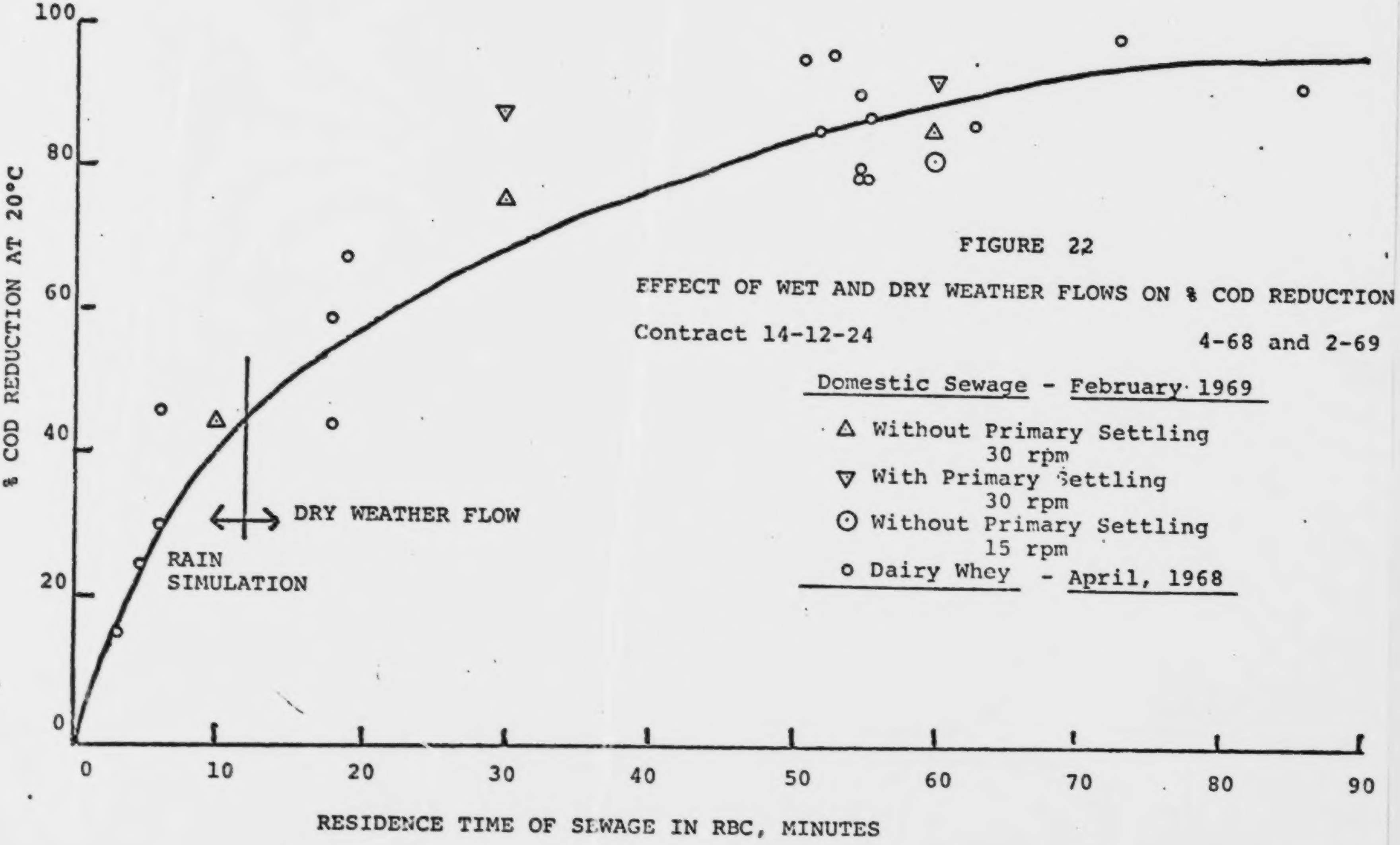


FIGURE 22

EFFECT OF WET AND DRY WEATHER FLOWS ON % COD REDUCTION

Contract 14-12-24 4-68 and 2-69

SOLIDS

As shown in Table F-4 of Appendix F, suspended solids reduction through the RBC unit ranged from 50.7 to 91.4 percent. The volatile suspended solids removal was in the same range. Insufficient determinations were made to draw definite conclusions about the effect of hydraulic loading on suspended solids removal. However, subsequent tests have shown that, as with COD, an increased hydraulic load causes a loss in the performance of the unit.

Settleable solids analysis was used to provide some idea of the quantity of sludge produced through the unit, and an approximation of sludge volume which would have to be handled at the demonstration plant. The solids concentration of the sludge was not determined.

Solids sampling may not have been entirely representative due to variation in daily bio-sloughing. Overall, however, this variation was assumed to average out.

The average volume of sludge produced was determined by averaging the volumes of settleable solids. The lower flow rates tended to produce a greater volume of sludge per unit volume of waste flow, though the total volume of sludge produced per day would be higher at higher flow rates. The operation at lower disc rotation produced a lower volume of sludge.

At lower disc rotation, the RBC unit developed a heavier slime which retained most of the solids and excess biomass when disc velocity was increased. The volume of secondary sludge produced ranged from 8.2 to 21.6 gallons/1000 gallons.

Use of settleable solids and suspended solids data provided a means of making an approximation of solids content of the sludge. Using a 15 gallon per thousand gallon average sludge volume produced, and a 230 pounds of solids settled per million pounds added, provided a sludge with a solids concentration of 1.5%. The volatile solids content of the sludge, using average total suspended and volatile suspended solids was 74%. These results were indirect determinations to be verified in Phase III at the demonstration plant.

INFLUENCE OF DISC SPEED ON DISSOLVED OXYGEN

Table F-1 of Appendix F shows the influence of rotational disc speed on the dissolved oxygen (D.O.) maintained in the mixed liquor of the RBC system. In these instances, determinations were made at 15 and 30 RPM. Results obtained were to be considered for the demonstration RBC unit in ascertaining the maintenance of the highest possible levels of dissolved oxygen prior to, during, and after any storm overflow event.

Depending on the mixed liquor temperature, the D.O. level of the raw waste was found to vary between 0.0 to 5.4 mg/l. The median was normally 0.8 mg/l. When the RBC unit was run at 15 RPM, the dissolved oxygen level of the effluent was marginally close to or lower than the raw influent. Thus, less than adequate aeration probably occurred at the 15 RPM disc speed for the organic loading range of the Municipal Sewage Plant.

Alternatively, when the unit was run at 30 RPM, the D.O. content of the effluent was always substantially higher than the influent. In effect, it was concluded that sufficient dissolved oxygen was being maintained in the mixed liquor to satisfy the oxygen demand of the microbial population of the RBC system.

NITROGEN

The discharge of ammonia and organic nitrogen places an oxygen demand on any receiving body of water. Discharge of nitrate in high concentration, along with phosphorus, can cause algae problems. Ideally, all of the nitrogen should be removed, controlled, or should not be discharged into a holding basin at a rate faster than it can be harvested from the water.

Figure 23 shows the levels of nitrogen removed as a function of COD removed. The pounds per day of Kjeldahl nitrogen removed versus pounds per day of COD removed; gives a ratio of about 25 to 1 of COD removed (15:1, BOD: N). Neither the COD nor nitrogen was corrected to 20°C. At the loading rates of the tests an average of 40.5 mg/l nitrogen was introduced to the unit while the clarified effluent carried an average 24.7 mg/l. An overall average of 15.8 mg/l (37.7 percent) nitrogen was removed. If this is concentrated in the sludge produced at an assumed 15 gallons per thousand gallons (average value from the solids analysis) the nitrogen concentration in the sludge should be approximately 1200 mg/l. The nitrogen in the influent was about 47 percent ammonia

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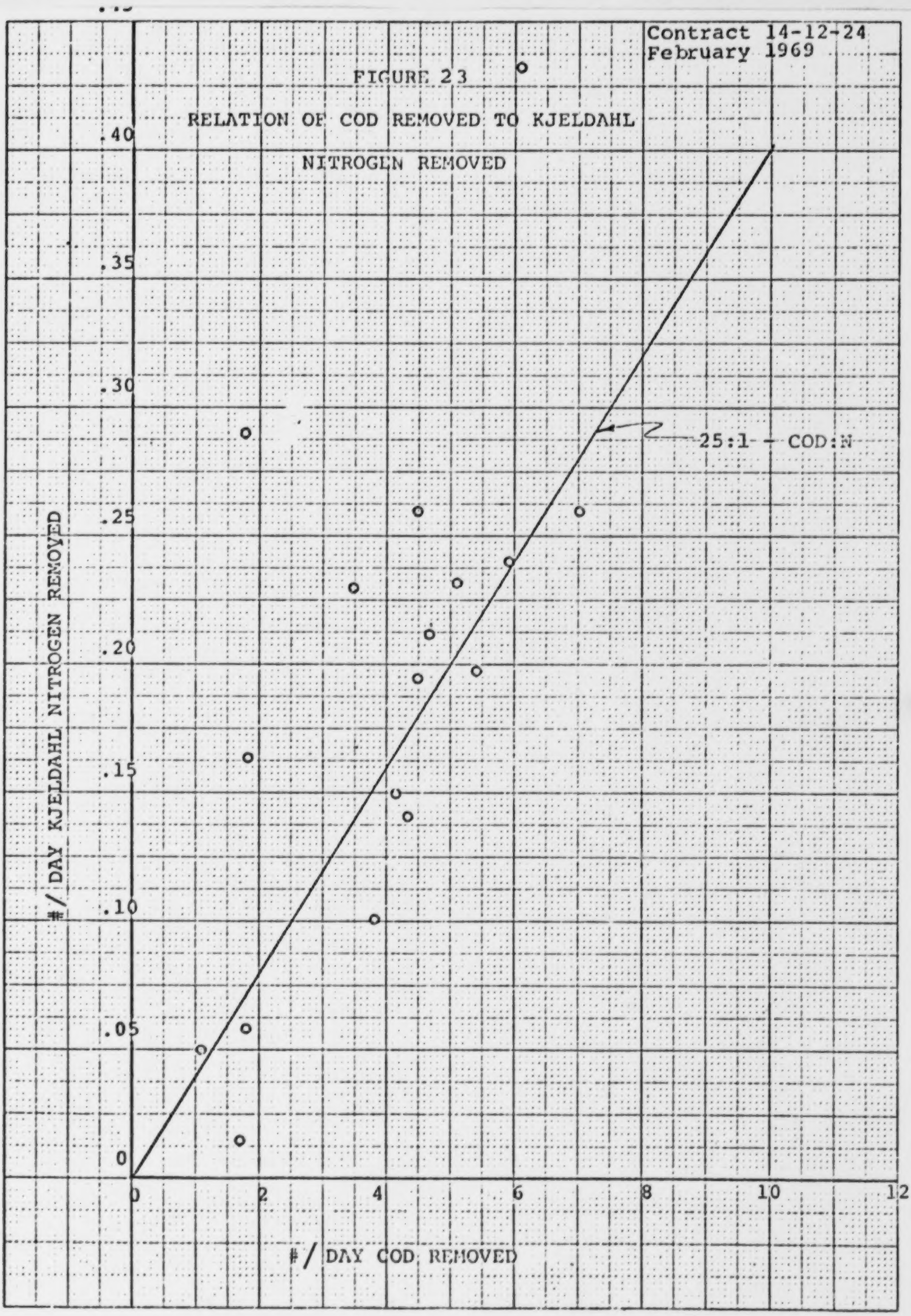

FIGURE 23

RELATION OF COD REMOVED TO KJELDAHL NITROGEN REMOVED

EUGENE DIETZGEN CO.
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20 X 20 PER INCH

and 52 percent organic nitrogen. In the effluent, the nitrogen was 65 percent ammonia and 35 percent organic nitrogen indicating some of the complex molecules had been broken down. The whole of the effluent nitrogen would have to be oxidized in a stream:

$$2NH_3 + \frac{9}{2} O_2 \longrightarrow 2 NO_3^- + 3H_2O$$

The conversion of ammonia to nitrate requires 4.57 parts oxygen to one part nitrogen. So the oxygen demand due to nitrogen was 24.6 x 4.57 or 113 mg/l nitrogenous oxygen demand. The RBC effluent was about twice as high in Kjeldahl nitrogen as the effluent from the Milwaukee Sewage Treatment Plant. The influent nitrogen concentration published was also 25% lower than the results analyzed here. At lower flow rates, it is expected that removals in the RBC unit would compare more favorably with Metropolitan Sewerage Commission analysis.

PHOSPHORUS

The total phosphorus introduced to the RBC unit was about 8.5 mg/l, half of which was dissolved phosphorus. Most of the dissolved phosphorus was ortho-phosphate. Total phosphorus removal through the unit averaged 53 percent (not corrected to 20°C). If the phosphorus removed is assumed concentrated in 15 gallons per thousand gallons of sludge, the total phosphorus concentration in the sludge would be about 300 mg/l. The 4 mg/l phosphorus in the effluent would have to be removed if this were the only secondary treatment being used.

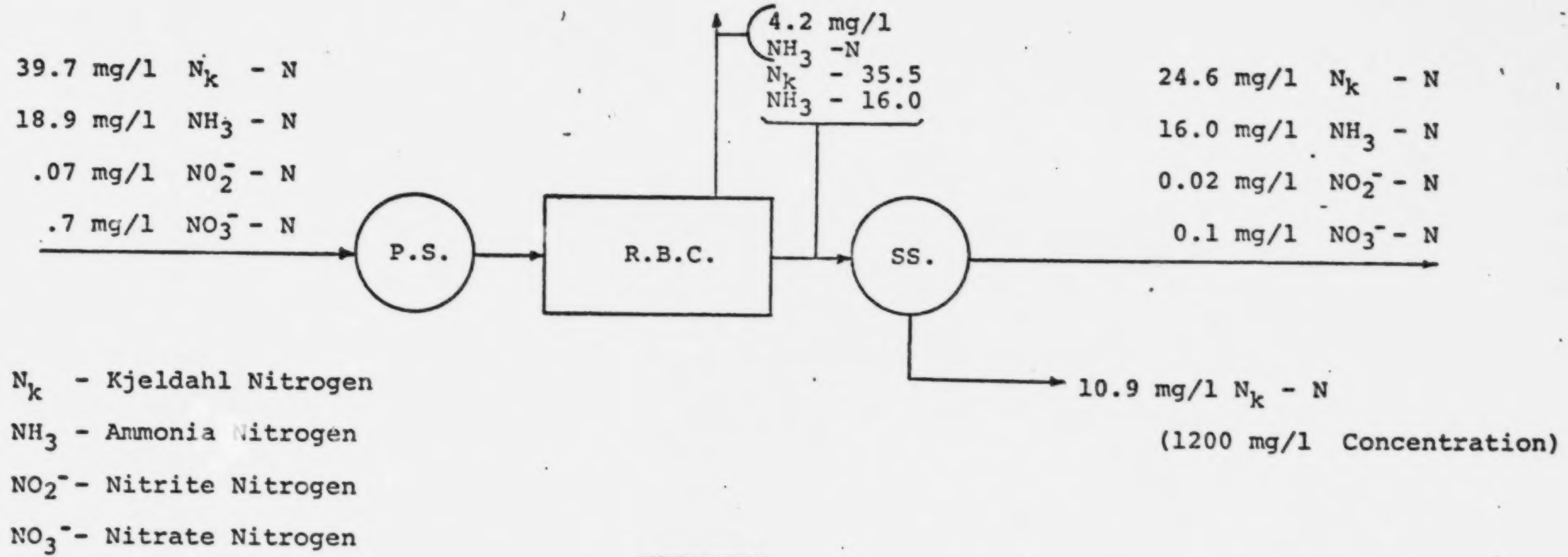
Increased retention time in the unit would improve removal by probably only by 1 mg/l, because the phosphorus available is in excess of the biological requirement.

Figure 24 summarizes the distribution of nitrogen and phosphorus through the RBC system. Averages of all analyses were used, so the effluent concentrations include the values when high flow rates were used and poor treatment resulted.

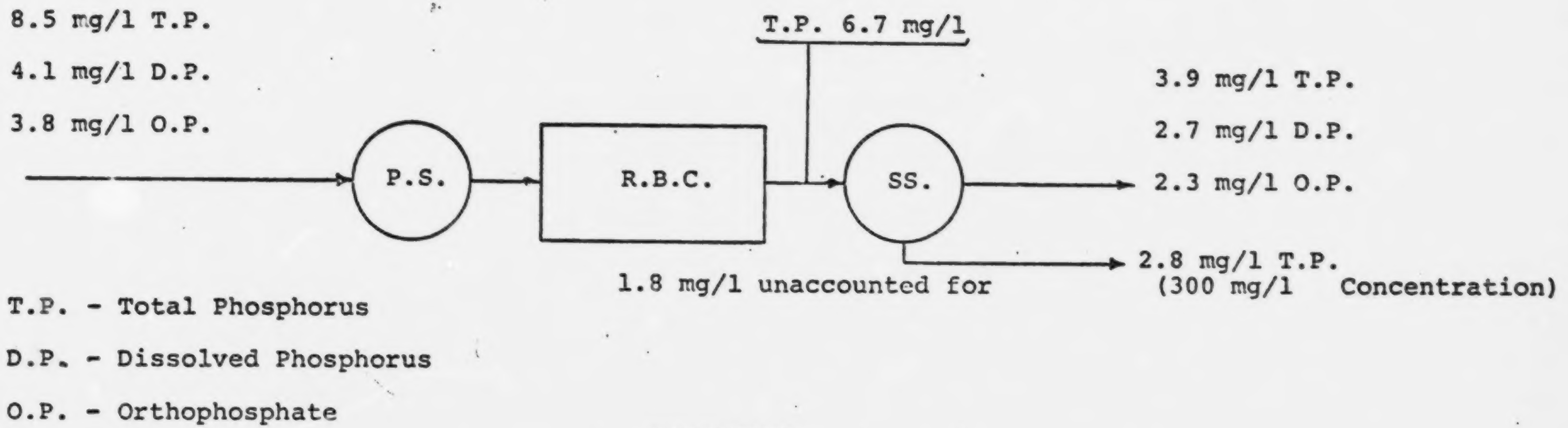
PRIMARY CLARIFIER

The primary clarifier removed an averaged 13% COD. In some instances, the COD decreased and sometimes increased through the clarifier. This may have been due to the fine screening step which had removed some of the settleable material. Not enough BOD, nitrogen, and phosphorus analyses were performed to draw any conclusions about their removal in the primary clarifier, but it would be expected that they would compare quite closely with the COD removal. The results of turbidity were comparable to the COD results. In other words, when turbidity was higher out than in, COD was also higher out than in.

In summary, testing at the Milwaukee Municipal Sewerage Plant demonstrated that domestic wastewater was effectively treated by the RBC process. Organic reduction measurements were evaluated over the loading range of 156 to 3579 lb COD per day per 1000 ft^3. At the average loading rate of 350 lbs COD per day per 1000 ft^3, 90% COD reduction was achieved. This


39.7 mg/l N_k - N
18.9 mg/l NH_3 - N
.07 mg/l NO_2^- - N
.7 mg/l NO_3^- - N
P.S.
R.B.C.
4.2 mg/l
NH_3 -N
N_k - 35.5
NH_3 - 16.0
SS.
24.6 mg/l N_k - N
16.0 mg/l NH_3 - N
0.02 mg/l NO_2^- - N
0.1 mg/l NO_3^- - N
10.9 mg/l N_k - N
(1200 mg/l Concentration)
N_k - Kjeldahl Nitrogen
NH_3 - Ammonia Nitrogen
NO_2^-- Nitrite Nitrogen
NO_3^-- Nitrate Nitrogen

NITROGEN


8.5 mg/l T.P.
4.1 mg/l D.P.
3.8 mg/l O.P.
P.S.
R.B.C.
T.P. 6.7 mg/l
SS.
3.9 mg/l T.P.
2.7 mg/l D.P.
2.3 mg/l O.P.
2.8 mg/l T.P.
(300 mg/l Concentration)
1.8 mg/l unaccounted for
T.P. - Total Phosphorus
D.P. - Dissolved Phosphorus
O.P. - Orthophosphate

PHOSPHORUS

FIGURE 24 . NUTRIENT DISTRIBUTION

reduction capacity was very nearly the same as that achieved in bench test with synthetic waste.

Data also showed that nitrogen was removed an a ratio of 1:25, nitrogen to COD, by the RBC unit. At the same time, approximately 53% of the influent phosphorus was removed under the conditions of the test program.

Again, as demonstrated in earlier bench tests, hydraulic overloading of the RBC unit for short periods did not adversely affect the efficiency of biological treatment. Normal organic reduction capacities returned very quickly once the unstable condition was reduced though the RBC.

SECTION V

DESIGN AND CONSTRUCTION

After the site evaluation in Phase I, the location at 8th and Montana Steeets in Milwaukee was selected for the demonstration for these reasons:

- The storm runoff would provide a flow rate of one million gallons per day during storms.
- Continuous dry-weather flow was available in the area.
- An 11-foot drop in the sewer grade existed in one of the manholes. This was sufficient to provide gravity flow through the demonstration plant.
- Several vacant lots on Montana Street were available for the plant and auxiliary equipment.
- Sewage at the site was primarily domestic with negligible industrial waste. Approximately 1,000 persons lived in the area. There were two schools. On the basis of flow measurements at the site, the RBC plant was designed for a dry-weather flow (DWF) of 50,000 gpd.

PLANT DESIGN

The demonstration site included the building to house the demonstration plant, the diversion manhole, and the discharge manhole structures. In the original plan, the building was to be underground with only a service entrance and control room above ground.

Construction bids on the proposal for an underground building showed that a re-design of the plant was necessary to keep the cost within contract specifications. The plant elevation was raised to reduce excavation and construction costs. A lift station to pump the entire combined sewer flow up to the higher elevation was required, however. The maximum measured storm flow, 50 cubic feet per second or 22,800 gpm, called for large pumps and motors. A "trade-off study" was made to compare the cost of the pump station with the cost of elevating the RBC plant. The study showed that the plant could be raised 14 feet above the original design. At high water level in the pump chamber, the storm pumps would pump against a 13-foot static head. A submersible pump designed for 50 gpm would pump all the dry-weather sewage flow to the RBC plant. Additional pumps of 40 and 75 HP was determined to be sufficient for maximum measured storm flow.

The revised RBC demonstration plant building was 60 feet by 21 feet, covering a 12-foot deep excavation for the RBC assembly (Figure 25). The pump well was 24 feet deep. The walls of the building were made of concrete blocks down to 2 feet below ground level. Below that, the walls of the excavation were poured concrete. The roof, about 10 feet above ground was wood with asphalt paper covering.

The plant included a surge tank with circular discharge orifices for flow measurement and control. The inlet structure used 36" concrete pipe; the outlet, 30" pipe.

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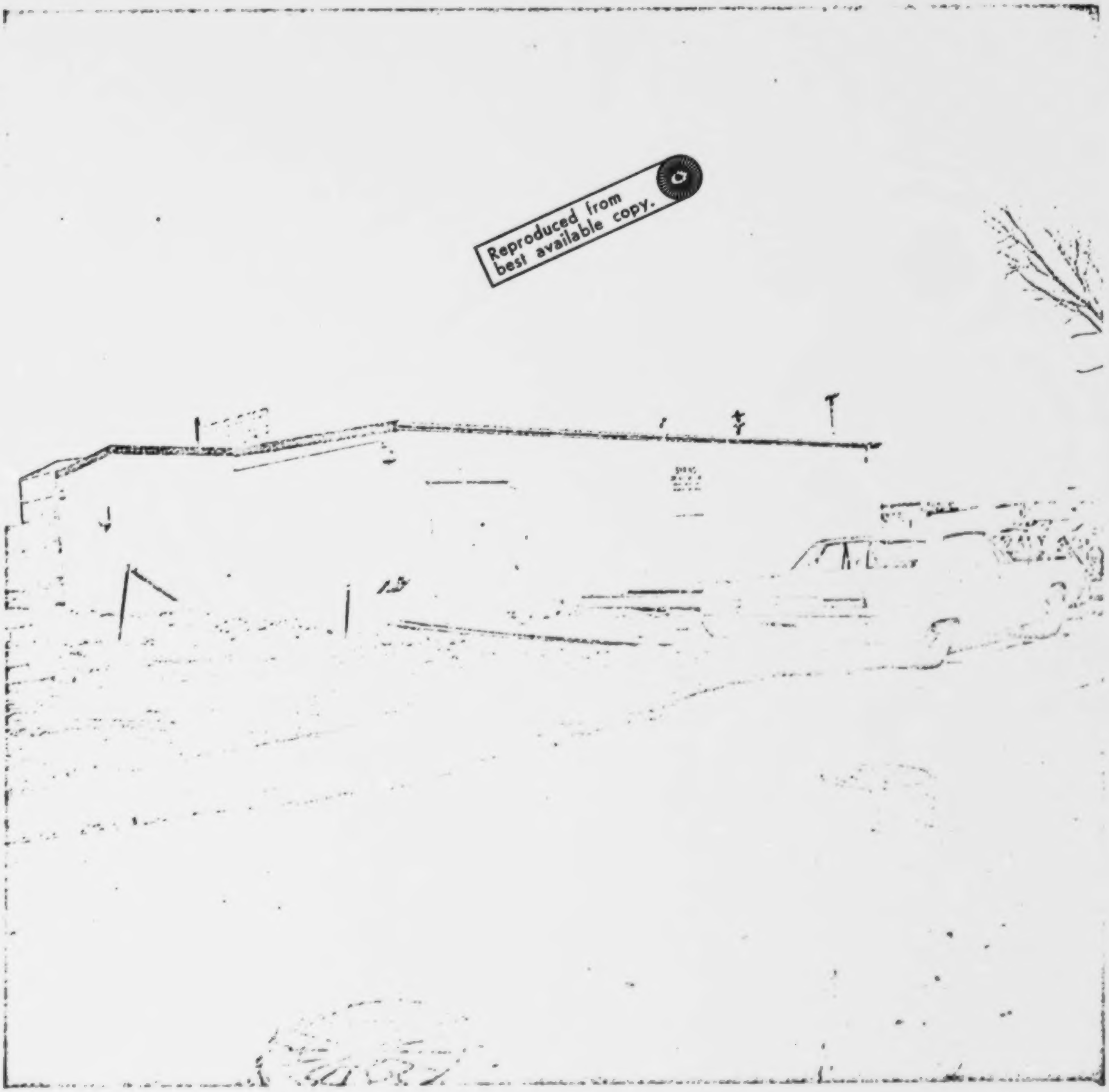


FIGURE 25

RBC DEMONSTRATION BUILDING

THE RBC BAYS

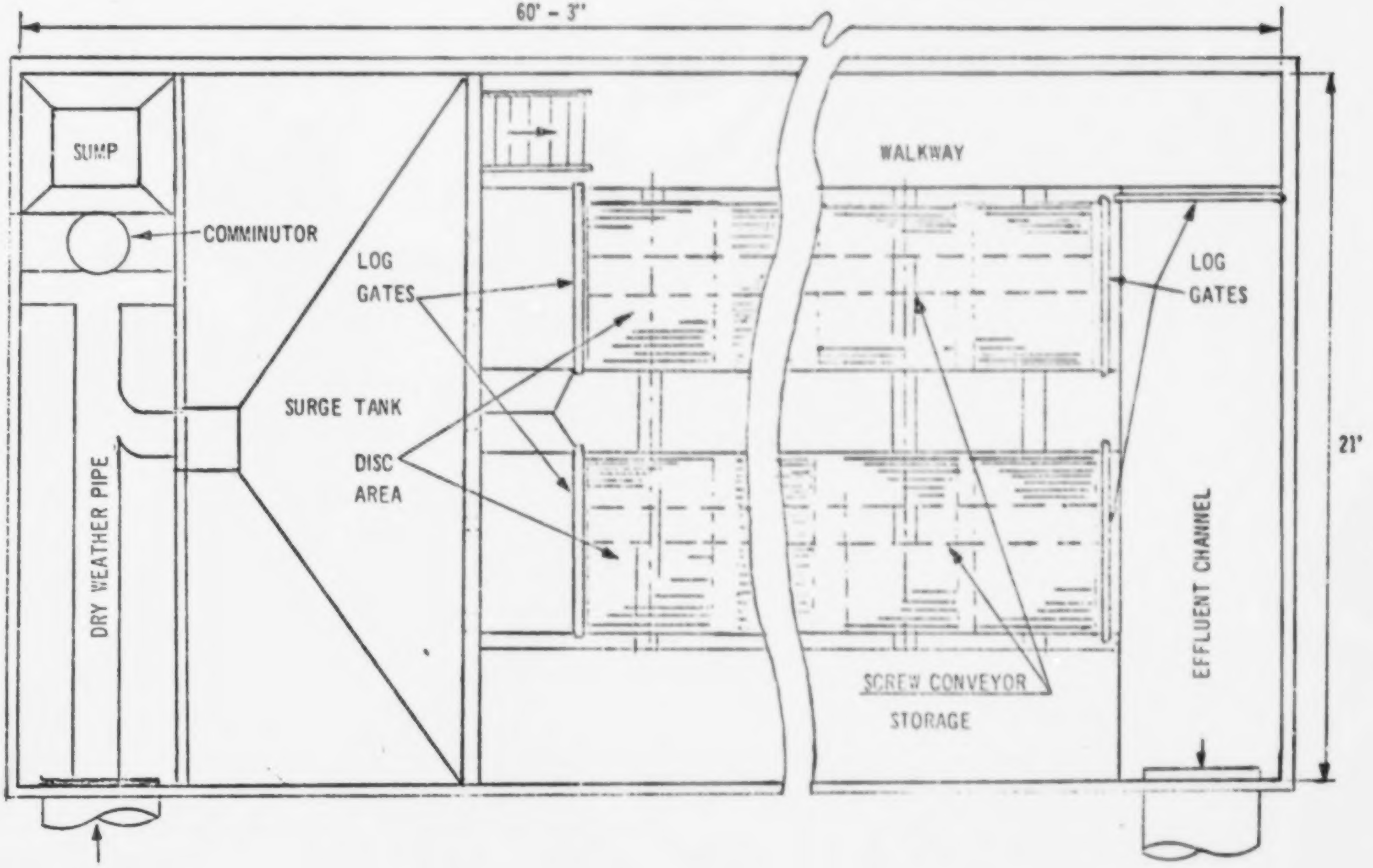
As shown in Figure 26, the RBC installation was hydraulically divided into two channels or bays. Each bay held 12 disc-shaft assemblies in series. Every disc-shaft assembly contained 85 aluminum discs with a diameter of 3 feet and thickness of 0.062 inch. Discs were spaced 1/2 inch apart with metal washers; every disc shaft was 54 inches long. A view of the installed RBC system is shown in Figure 27.

The size and number of discs were chosen to provide 28,300 sq. ft., the effective surface area requirement for biological growth determined during Phase I.

At every row of discs, the shaft in each bay was turned by a single hydraulic motor placed at one end of the row. The motors, mounted on vertical alignment plates, protruding into the walkway for easy servicing. The motors were connected in a parallel circuit. A 15-horsepower hydraulic pump in a control room supplied the high pressure oil to drive the motors. To compensate for misalignment, each motor's torque was transmitted to the shaft by a flexible chain coupling. The speed (0 to 15 rpm) and rotational direction of the motors could be controlled at each one.

The side walls of the RBC bays extended to about 3 inches over the top of the 3-foot-diameter discs to contain the water during high flows. The bottom under every row of discs was contoured to receive the discs with about one inch clearance.

FIGURE 26. PLAN VIEW OF THE RBC DEMONSTRATION PLANT


60' - 3"
21'
SUMP
COMMINUTOR
DRY WEATHER PIPE
LOG
GATES
SURGE TANK
DISC
AREA
WALKWAY
LOG
GATES
SCREW CONVEYOR
STORAGE
EFFLUENT CHANNEL

Bio-Discs Installed in the RBC Demonstration Plant

Figure 27

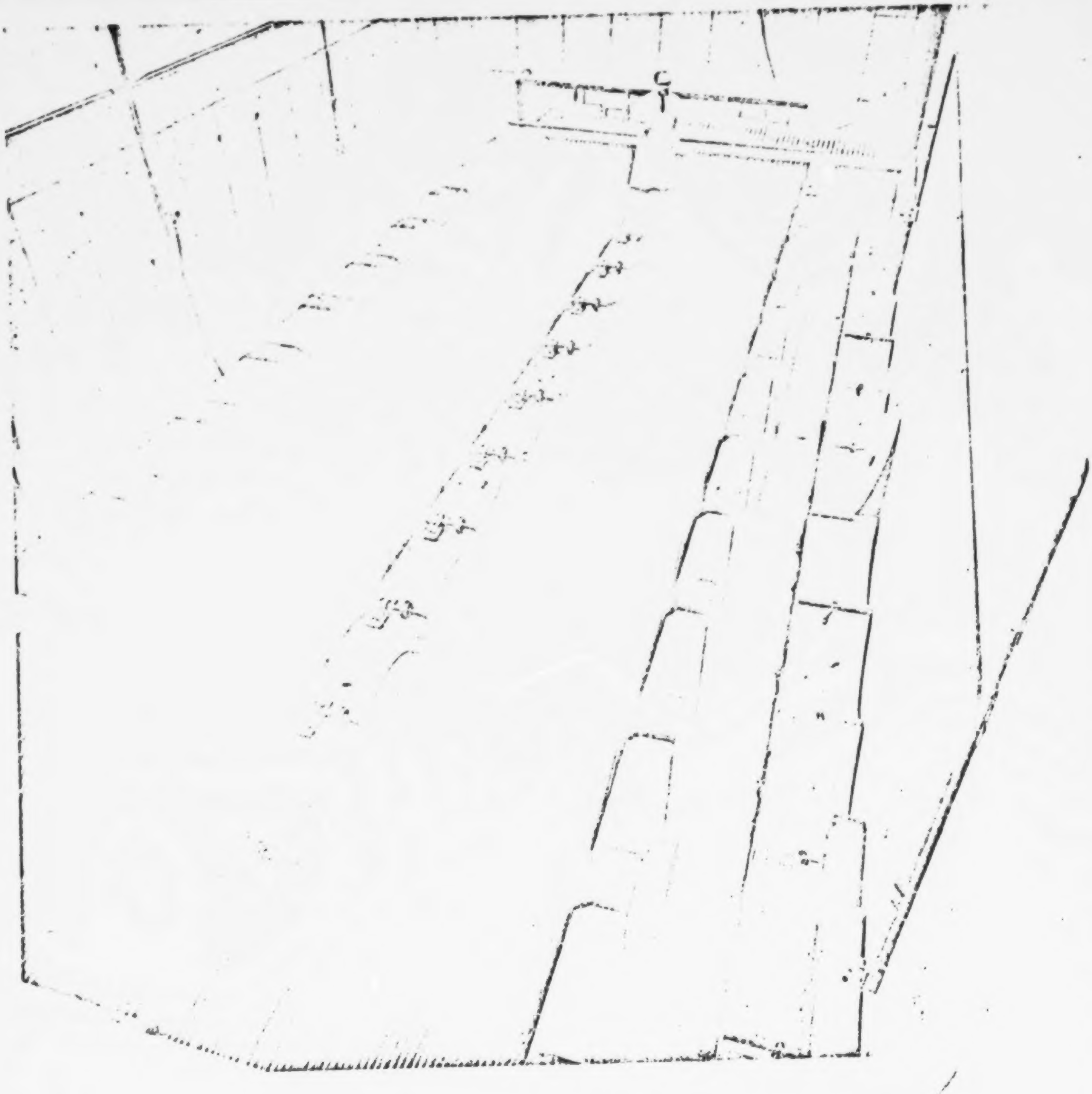
These contours were formed by three removable, precast-concrete blocks. Figure 28 shows the center blocks removed from the RBC bays and stacked along the south wall.

As shown in Figure 29, the 12-inch-diameter screw conveyor extended along the bottom of each RBC bay under the discs. This unit removed the sloughed settleable biomass from the channels. The plant was also operable without the conveyor when the center contoured concrete blocks were put in place.

Each screw conveyor was driven at the effluent end of the RBC bay by the same type of hydraulic motor that was used to drive the RBC discs. For both conveyors there was a sludge collection hopper. A 2-inch brass gate valve at the bottom was used to empty the hopper directly into the discharge channel.

When the plant was in operation, sewage passed through the rows of rotating discs and spilled over a weir at the effluent end. The treated sewage returned to the 30" sewer at manhole "B" (See Figure 4). During wet weather, the storm flow accumulated in the pump well until a nitrogen-operated pressure switch actuated a 16", 40-HP propeller pump. If the in-rushing storm flow was too great for the capacity of this pump, the level continued to rise, actuating a 20", 75-HP pump.

Together the two pumps had sufficient capacity to handle major storms. If the pumps were unable to handle the water, the level would rise to the overflow outlet in the 30" combined



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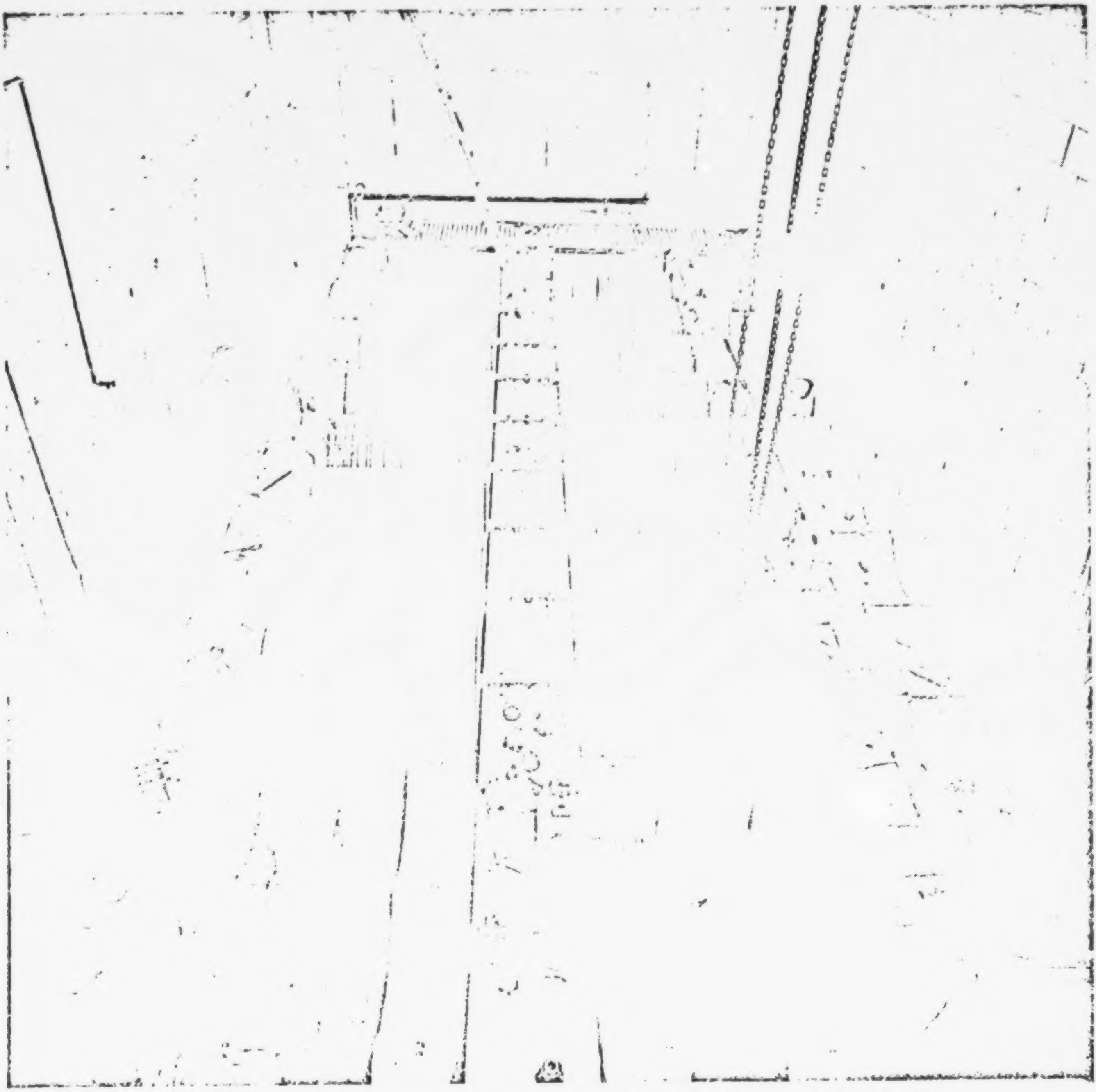
RBC Disc Bays and Removable Concrete Blocks
Figure 28



SCREW CONVEYOR INSTALLED UNDER BIO-DISC INSTALLATION

FIGURE 29

Reproduced from best available copy.

sewer and bypass the plant. The overflow outlet was a safeguard in case of power failure or exceptionally rare storms.

As shown in Figure 30, the water was pumped into the surge tank. When the water reached the orifices in the surge tank, it discharged an equal volume into both RBC bays. Energy dissipators were installed several feet away from the orifices to dissipate the energy of the water jets, so the biomass would not be washed off the first row of discs.

As wastewater came in contact with the biomass on the discs and in the water, organic matter was rapidly absorbed and removed from the wastewater, thereby reducing its BOD loading.

STORM FLOW MEASUREMENTS

Storm flow was measured in two places at the demonstration site -- (1) in a calibrated section of the 30" combined sewer in the street; (2) at a group of free-discharge orifices in the surge tank.

The calibrated section of the 30" combined sewer was upstream from the plant and carried 93% of the total flow to the plant. The other 7% entered the sewer between the calibrated section and the plant. Depth of the water was measured in that section. Flow was calculated by use of the Manning equation (See Appendix C).

In the plant, depth of water was measured at the free discharge orifices. There were ten 6-1/2-inch diameter, sharp-edged circular orifices in the wall of the surge tank -- five for

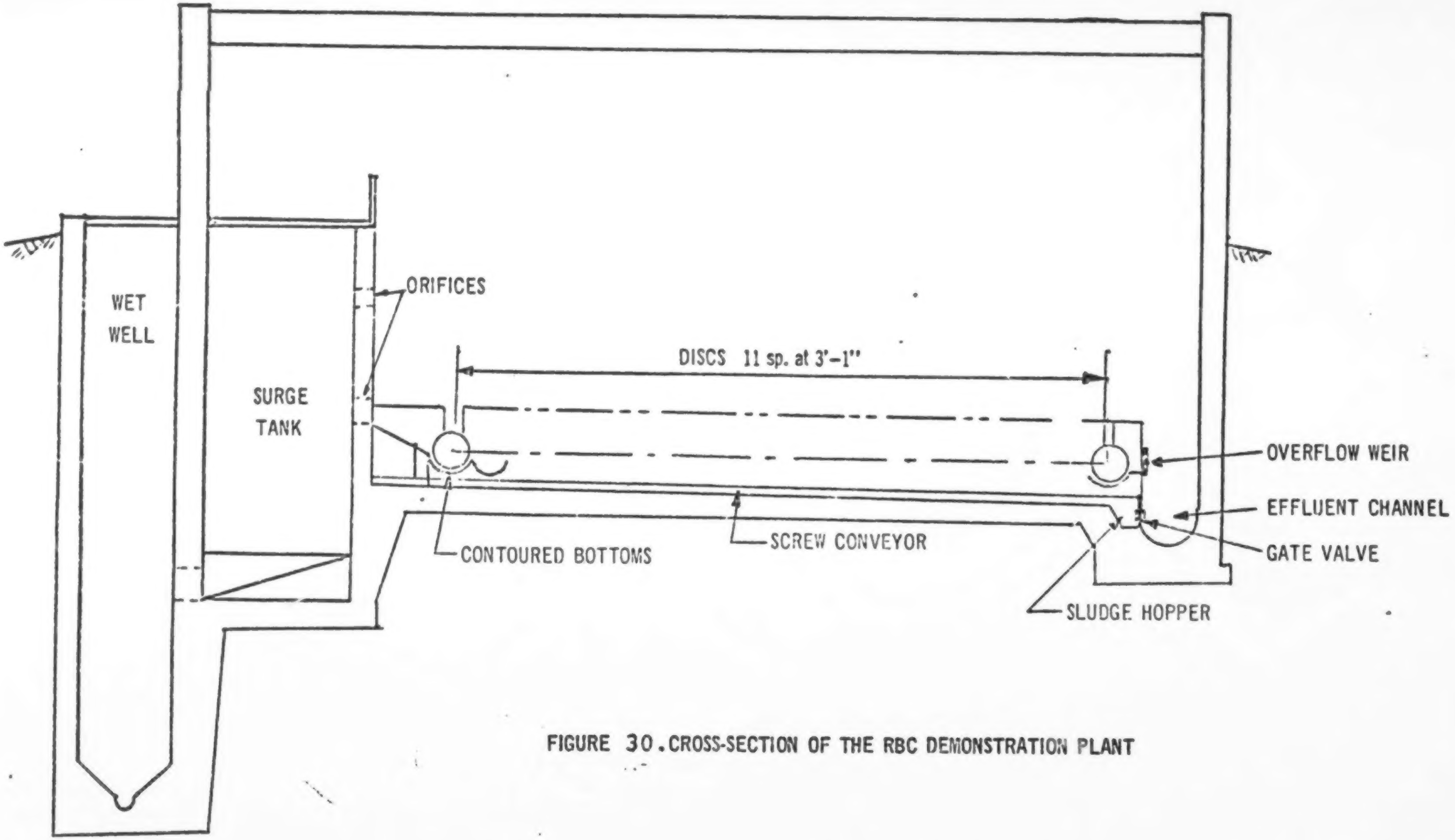

ORIFICES
WET WELL
SURGE TANK
DISCS 11 sp. at 3'-1"
OVERFLOW WEIR
EFFLUENT CHANNEL
GATE VALVE
SLUDGE HOPPER
SCREW CONVEYOR
CONTOURED BOTTOMS

FIGURE 30. CROSS-SECTION OF THE RBC DEMONSTRATION PLANT

each RBC bay. Maximum flow through them was about 30 feet per second. Excess water flowed over rectangular weirs above the circular orifices. Flow for low heads which did not cover the orifices was approximated by use of free surface weir discharge formulas (See Appendix C).

Depth measurements were actually measurements of pressure employing the gas pressure equilibrium principle described in Appendix C. Nitrogen gas was bled through independent lines to the sewer and the surge tank. Measurements in both the sewer and surge tank were continuously recorded. A typical sewer flow meter chart is shown in Figure 31.

PUMP CONTROLS

Another nitrogen line, similar to those described in the previous paragraph, went to the pump well where the head of water was monitored. The head was indicated on a non-recording pressure gauge. The pressure in this nitrogen line controlled three pressure-sensitive switches for the pumps at the pump well. At low water levels, the dry-weather pump alone moved water from the pump well to the surge tank. As the water level rose in the pump well, the 40-horsepower pump was turned on. When the water rose still higher, the 75-horsepower pump was turned on. As the water level fell, the pumps were turned off in reverse sequence.

Figure 32 shows the control panel. The three pressure-sensitive switches are at the left. Figure 33 is a schematic diagram of the nitrogen lines to the pump well and the sewer.

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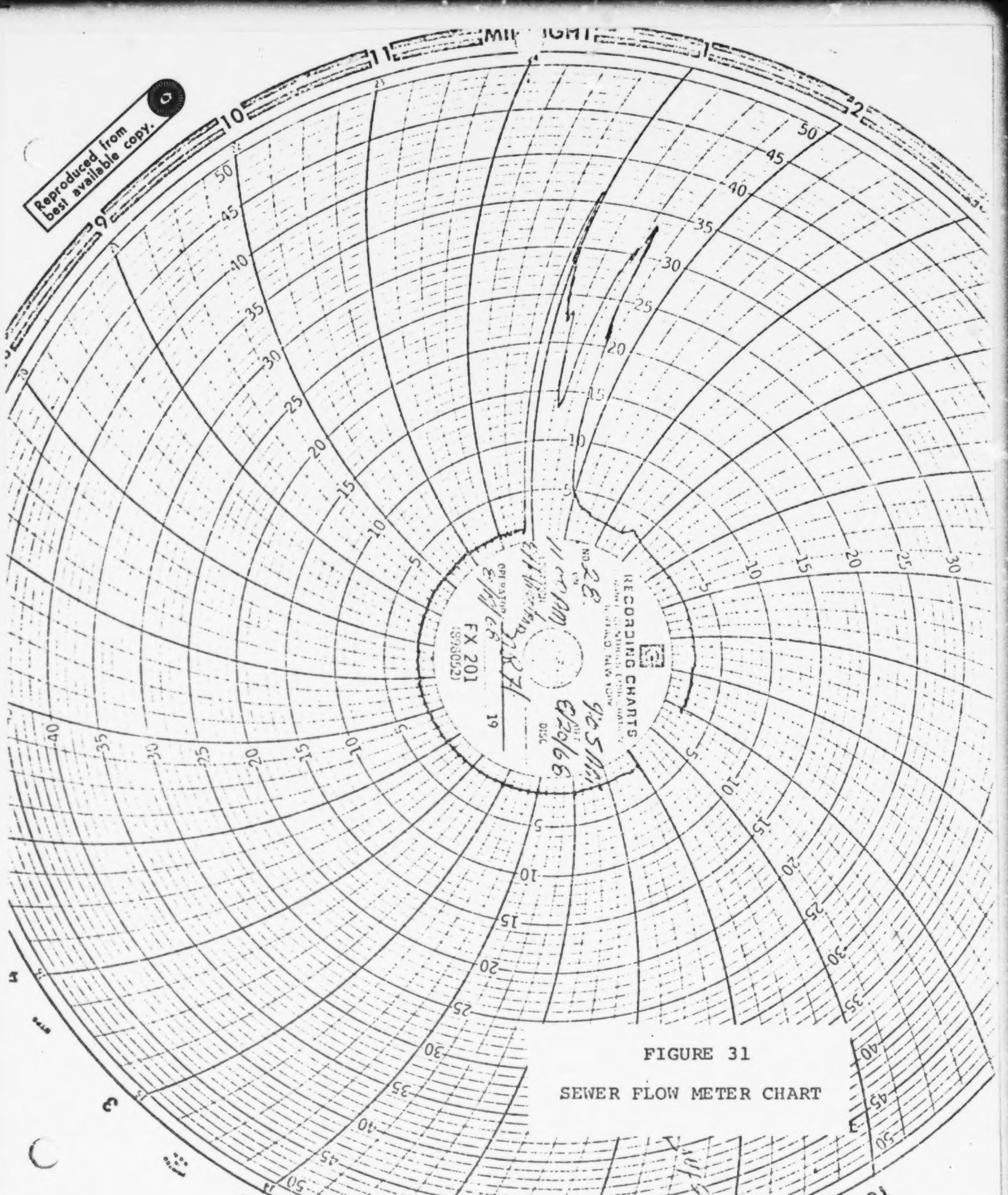

FIGURE 31

SEWER FLOW METER CHART

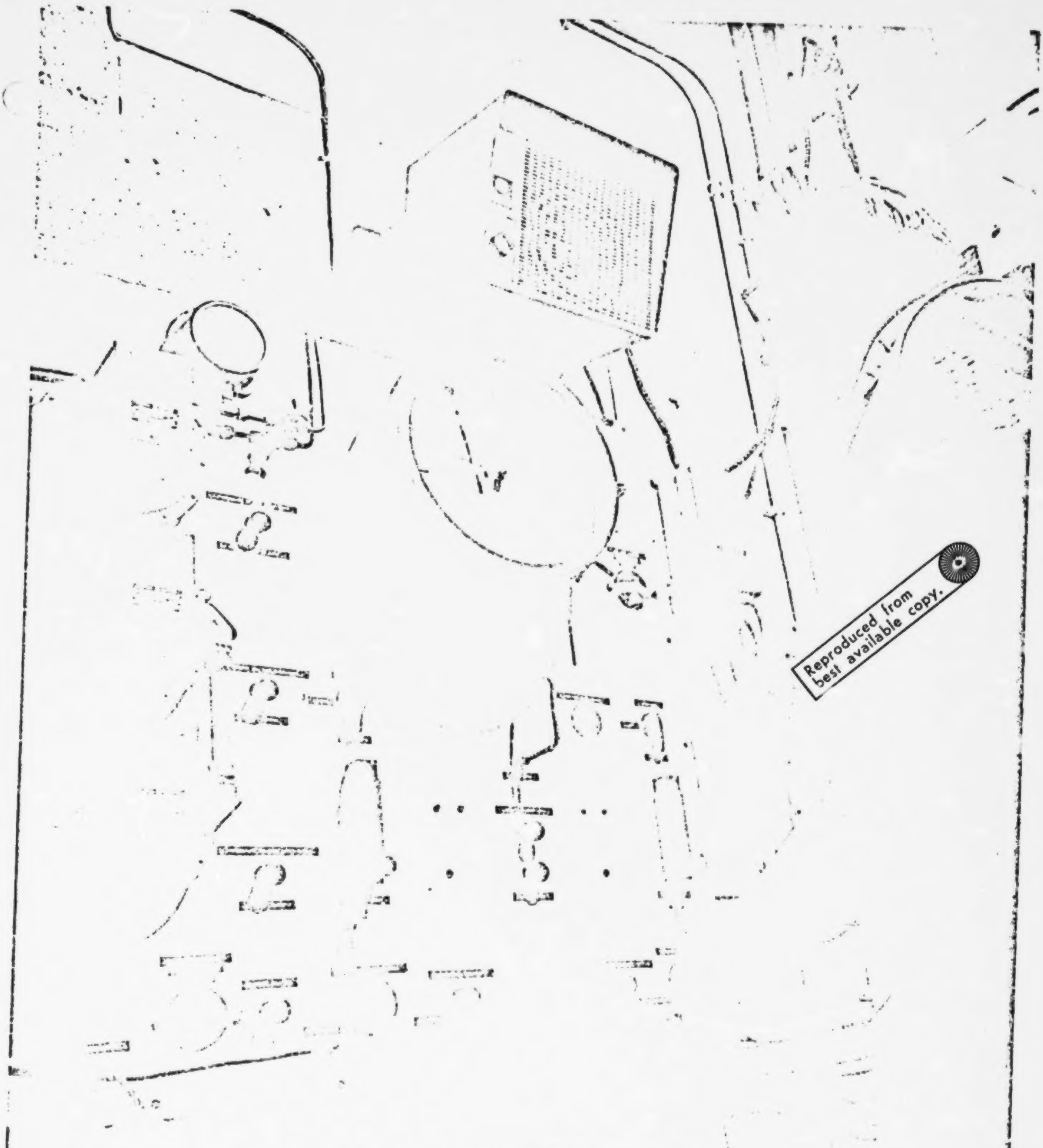

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FIGURE 32

CONTROL PANEL FOR BIO-DISC DEMONSTRATION PLANT

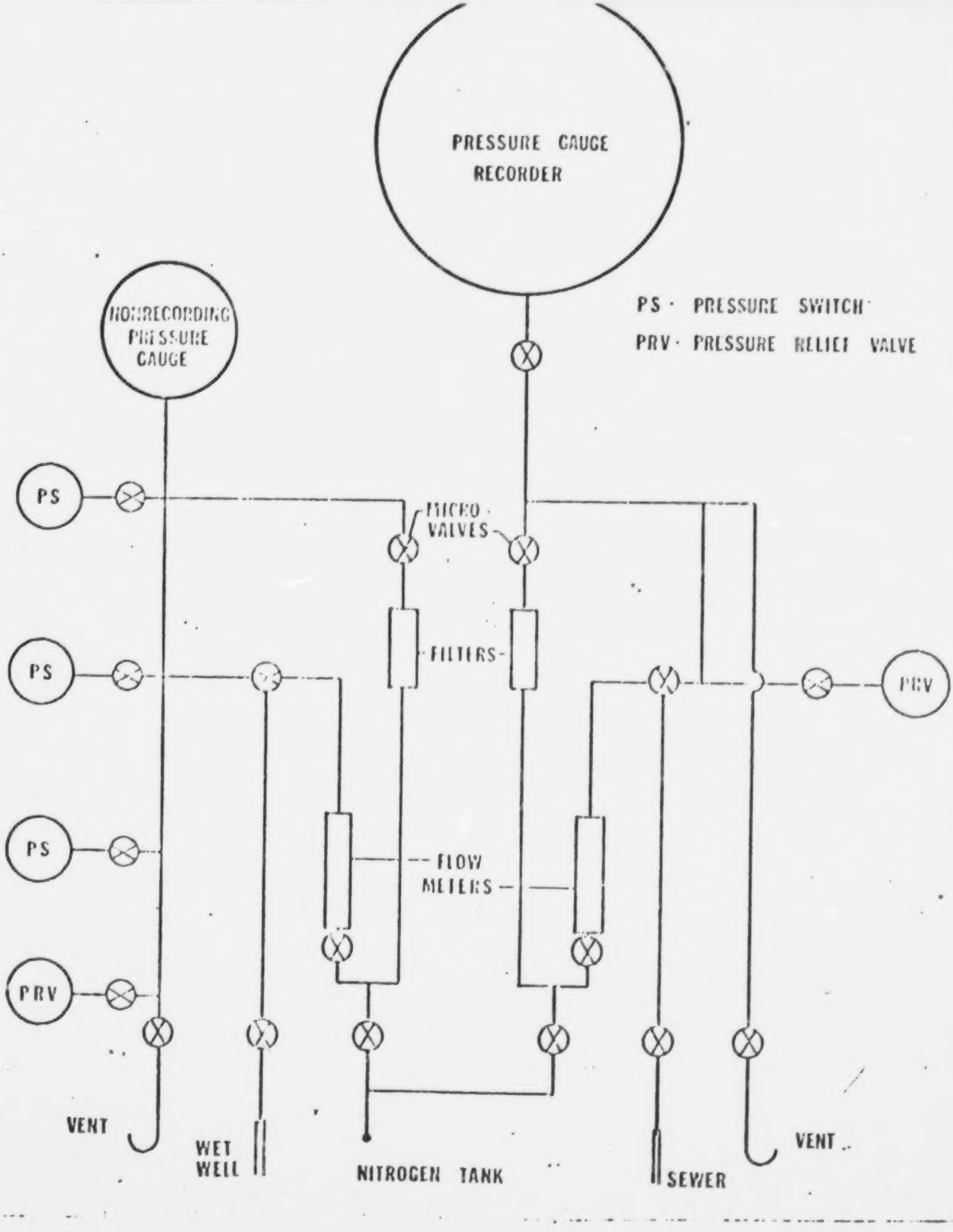

PRESSURE GAUGE RECORDER
NONRECORDING PRESSURE GAUGE
PS - PRESSURE SWITCH
PRV - PRESSURE RELIEF VALVE
PS
PS
PS
PRV
PRV
MICRO VALVES
FILTERS
FLOW METERS
VENT
WET WELL
NITROGEN TANK
SEWER
VENT

FIGURE 33

SCHEMATIC DIAGRAM OF CONTROL SYSTEM

SECTION VI

RAINFALL MEASUREMENTS

OCCURRENCE

Rainfall data for 38 rain events were recorded at the Eighth and Montana Streets test site. For purposes of this report, no attempt was made to complete a detailed analysis of all these events. Rain data was summarized and presented in Tables G-1 through G-56 of Appendix G along with monthly tabulations of rain events.

RAINFALL ANALYSIS

The characteristics of the combined sewer overflow to the RBC are described for several representative storms in terms of duration and intensity of the storm monitored. Wet weather data for these selected rain events are presented in Tables 5 and 6. Tabulated also in Table 5 are additional data on lag time between rains, time of occurrence, and rain intensity. Each of the rain events was evaluated over a time span of 100 to 140 minutes. This period was governed by the sampling devices of the demonstration plant. Test data has historically shown this span to be the norm for the demonstration area.

Effects and upsets in system capability during this time span were evaluated in terms of COD and BOD and settleable solids in accordance with Standard Methods, 12th Edition.

TABLE 5

RBC DEMONSTRATION PLANT - 8TH & MONTANA STREET SITE, MILWAUKEE, WIS.
RAINFALL & WET WEATHER SEWER FLOW DATA (1)

DATE	PREVIOUS DRY TIME HRS	TIME	DURATION HOURS	INTENSITY (3) IN/HR		TOTAL RAINFALL		FLOW RATE, GPM		TOTAL FLO GALLONS
				MAX	AVE	IN	GAL	MAX	AVE	
29 Jun, '69 (2)	51	6:30 AM	2:00	0.24	0.17	0.34	322,000	2,400	1,377	224,400
2 Jul, '69	40	10:45 PM	1:00	1.2	0.28	0.28	265,000	5,100	1.546	145,300
29 Sep, '69	342	6:10 AM	4:50	2.4	0.96	0.80	800,000	-	490	185,000
19 Oct, '69	124	4:05 AM	6:30	0.18	0.05	0.30	300,000	3,000	480	105,577
31 Oct, '69	276	2:30 PM	13:00	0.11	0.02	0.31	310,000	955	534	114,900

---

(1) 93% of Drainage Area

(2) COD Data

(3) For evaluating purposes of this report, the selected rain events are typed as follows:

29 June, 1969 - a uniform rain event
2 July, 1969 - a variable intensity rain event
29 Sept, 1969 - an intense rain event
19 Oct., 1969 - a moderate level rain event
31 Oct., 1969 - a moderate level rain event

(4) See also Appendix E

TABLE 6

WET WEATHER ORGANIC LOADING DATA

AS BOD_5 (1)

RAINFALL DATE	PREVIOUS DRY TIME HRS	OCCURRENCE	DURATION HRS	RAIN INTENSITY IN/HR MAX	RAIN INTENSITY IN/HR AVE	LOADING RATE LBS/DAY MAX	LOADING RATE LBS/DAY AVE	TOTAL LOAD LBS
29 Jun, '69 (2)	51	6:30 AM	2:00	0.17	0.24	2760	1499	170
2 Jul, '69	40	10:45 PM	1:00	1.2	0.28	4340	1352	88
29 Sep, '69	342	6:10 AM	4:50	2.4	0.96	--	1680	442
19 Oct, '69	124	4:05 AM	6:30	0.18	0.05	8507	970	148
31 Oct, '69	276	2:30 PM	13:00	0.11	0.02	3002	834	124

---

(1) 93% of Drainage Area

(2) COD Data

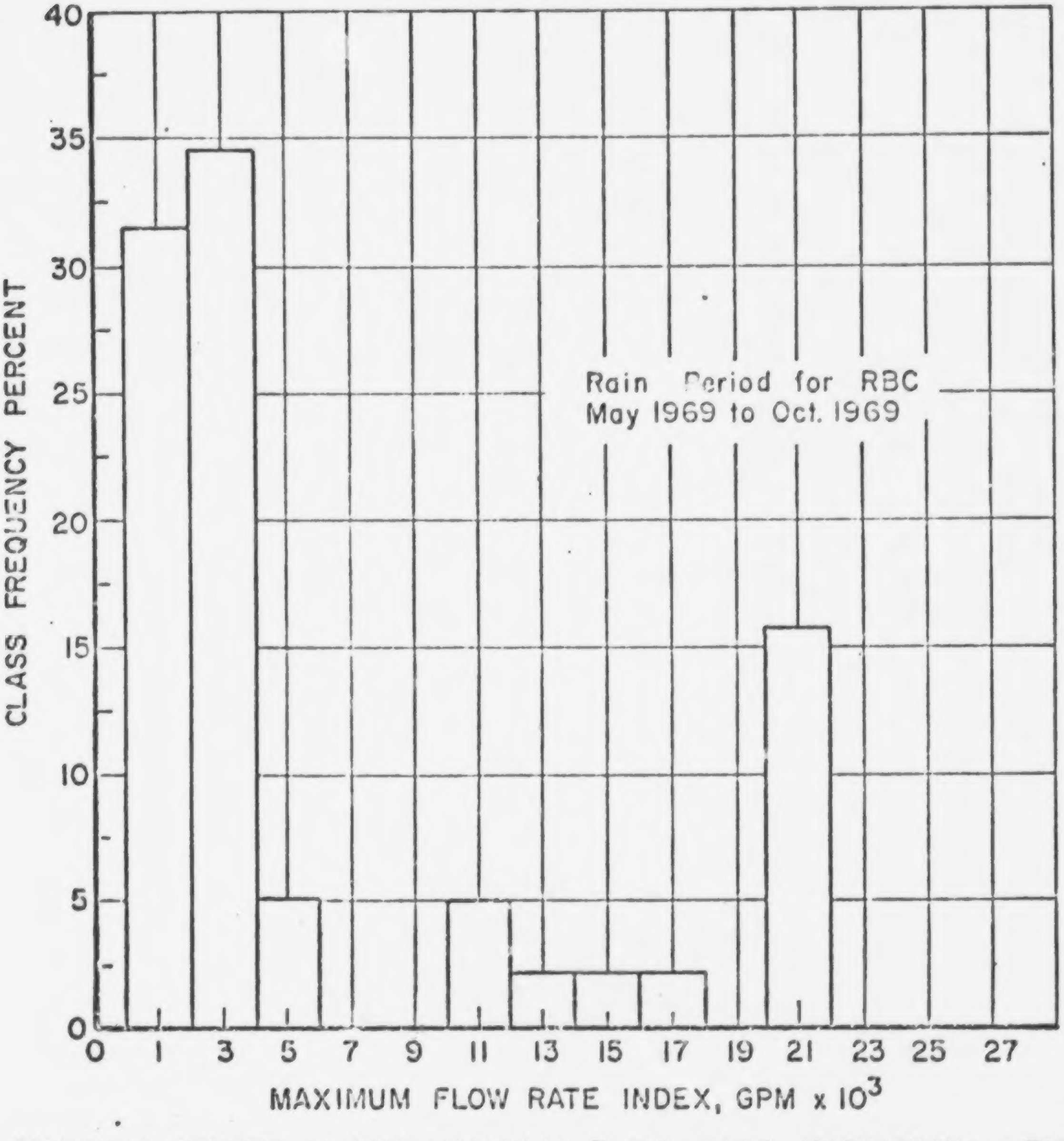
HYDRAULIC FLOW

As shown in the frequency plots of Figures 34 and 35, a maximum flow of 3,000 gpm was the dominant rain flow rate experienced by the RBC system. Fifty percent of the time (Figure 35) a median rain flow rate of 1,500 gpm maximum was the norm. At the same time, Figures 36 and 37 show that at least 50% of the total rainfall experienced by the RBC system had a volumetric load range of 120,000 ± 40,000 gallons.

Figure 38 indicated that half the rain events had a duration of 1.1 hours or less. As indicated in the scatter diagram (Figure 39) of these rain events, the shorter duration (0.1 to 1 hour) exhibited the highest rain intensity. Median rain intensity was 0.56 inches per hour. The converse was generally true of those rain events exceeding two hours, exhibiting a median rain intensity of 0.10 inches per hour. Maximum flow tended to occur 5 to 10 minutes after the onset of the storm. Average rainfall intensity of the demonstration area was 0.46 inches per hour.

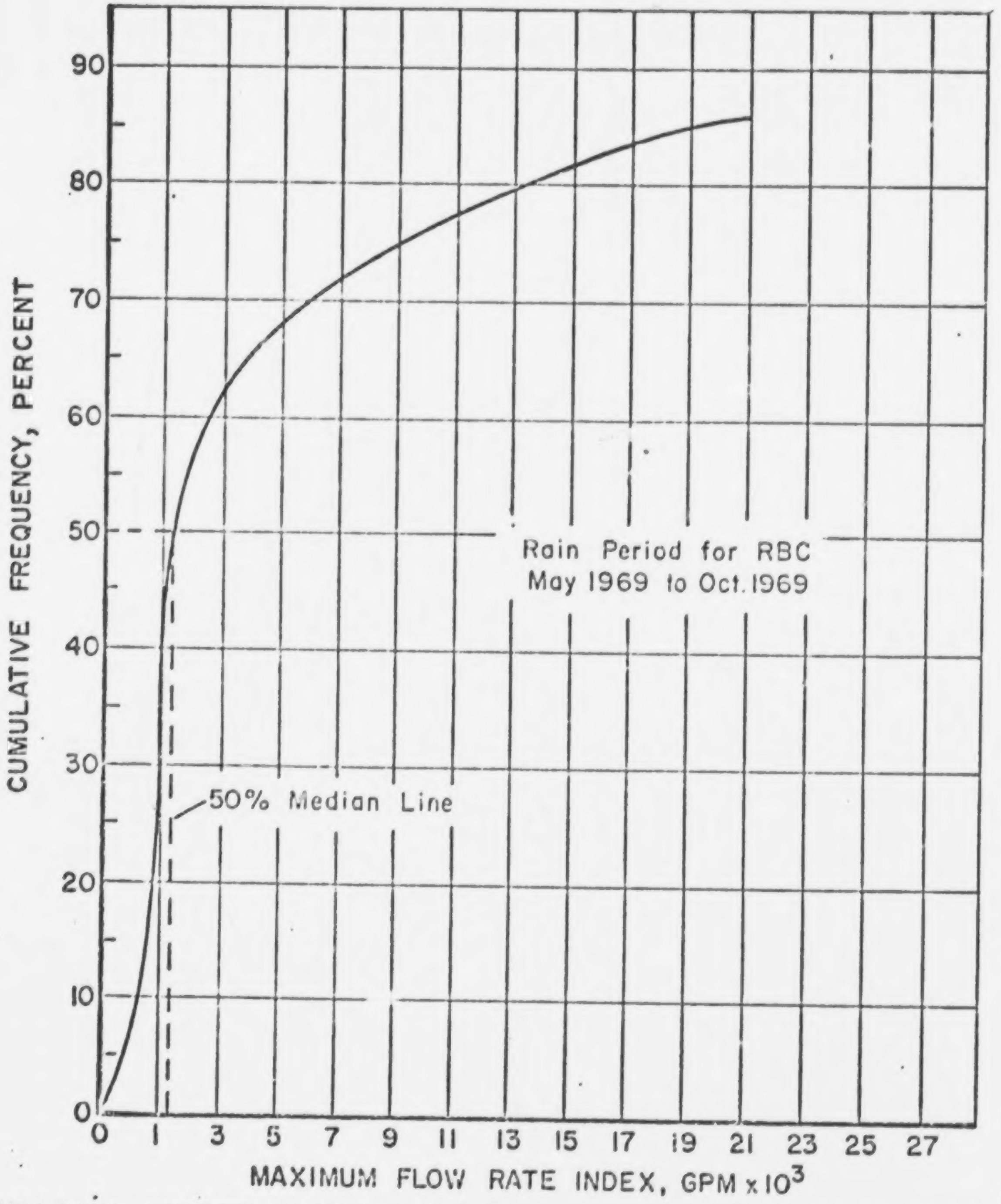
ORGANIC LOADING

Figure 40 shows that the additional organic pollution during the recorded rain events occurred predominantly at 188 lbs. as BOD (biochemical oxygen demand). More than 50% of the rain events contributed a sewer load of greater than 150 lbs. BOD.



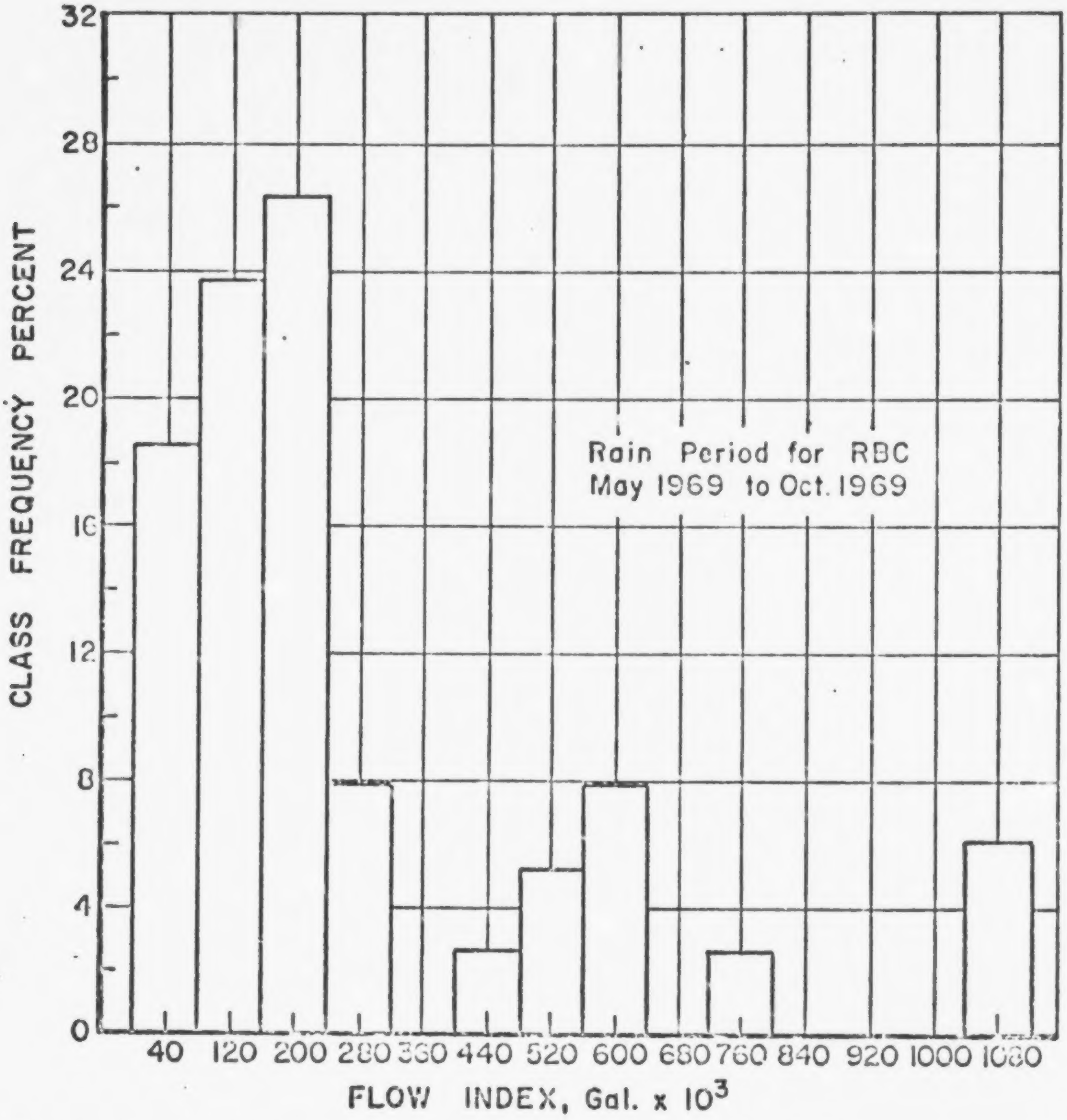
MONTANA STREET PLANT-MAXIMUM FLOW RATE FREQUENCY LEVEL

FIGURE 34



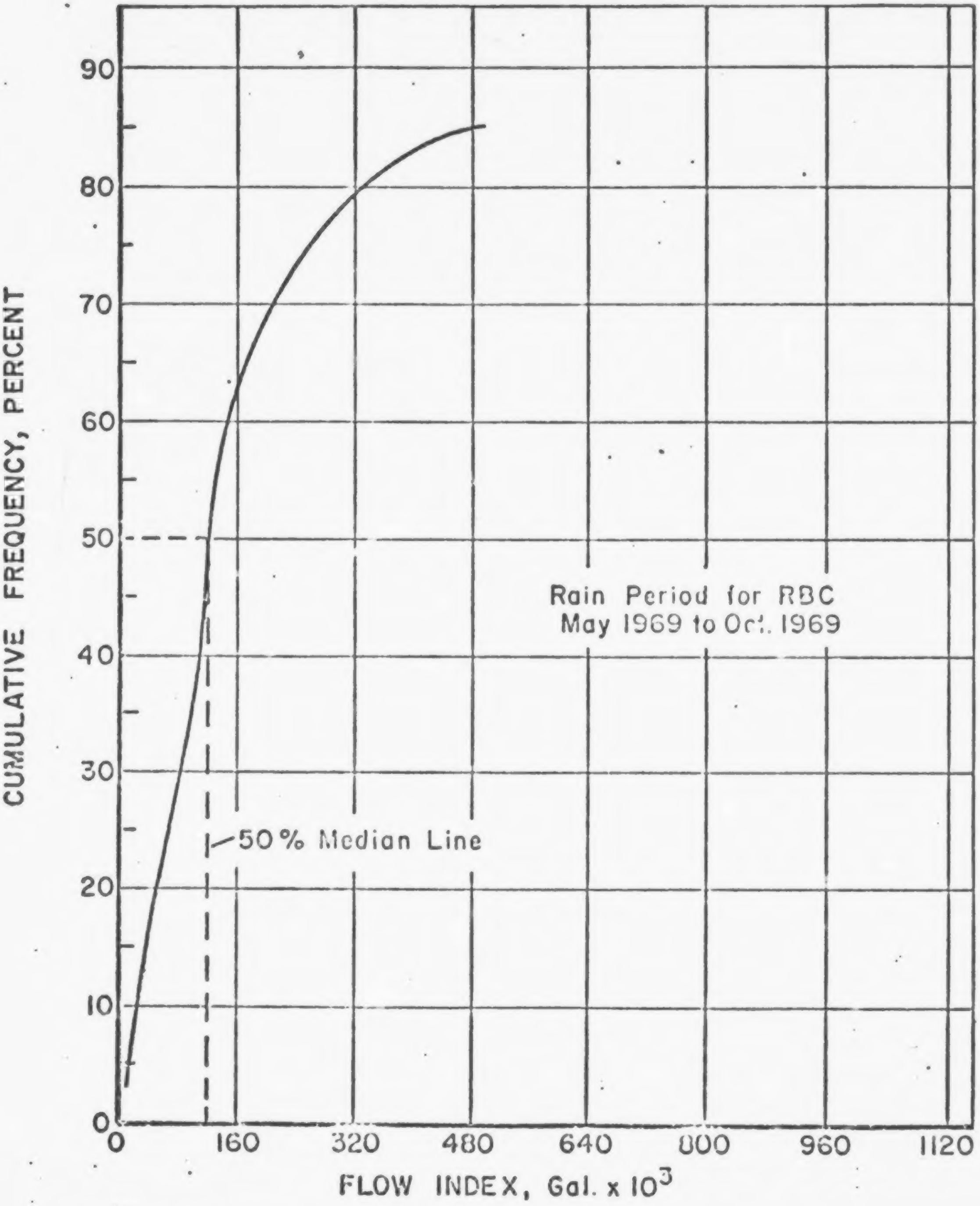
MONTANA STREET PLANT MAXIMUM FLOW RATE FREQUENCY PERCENTAGE

FIGURE 35



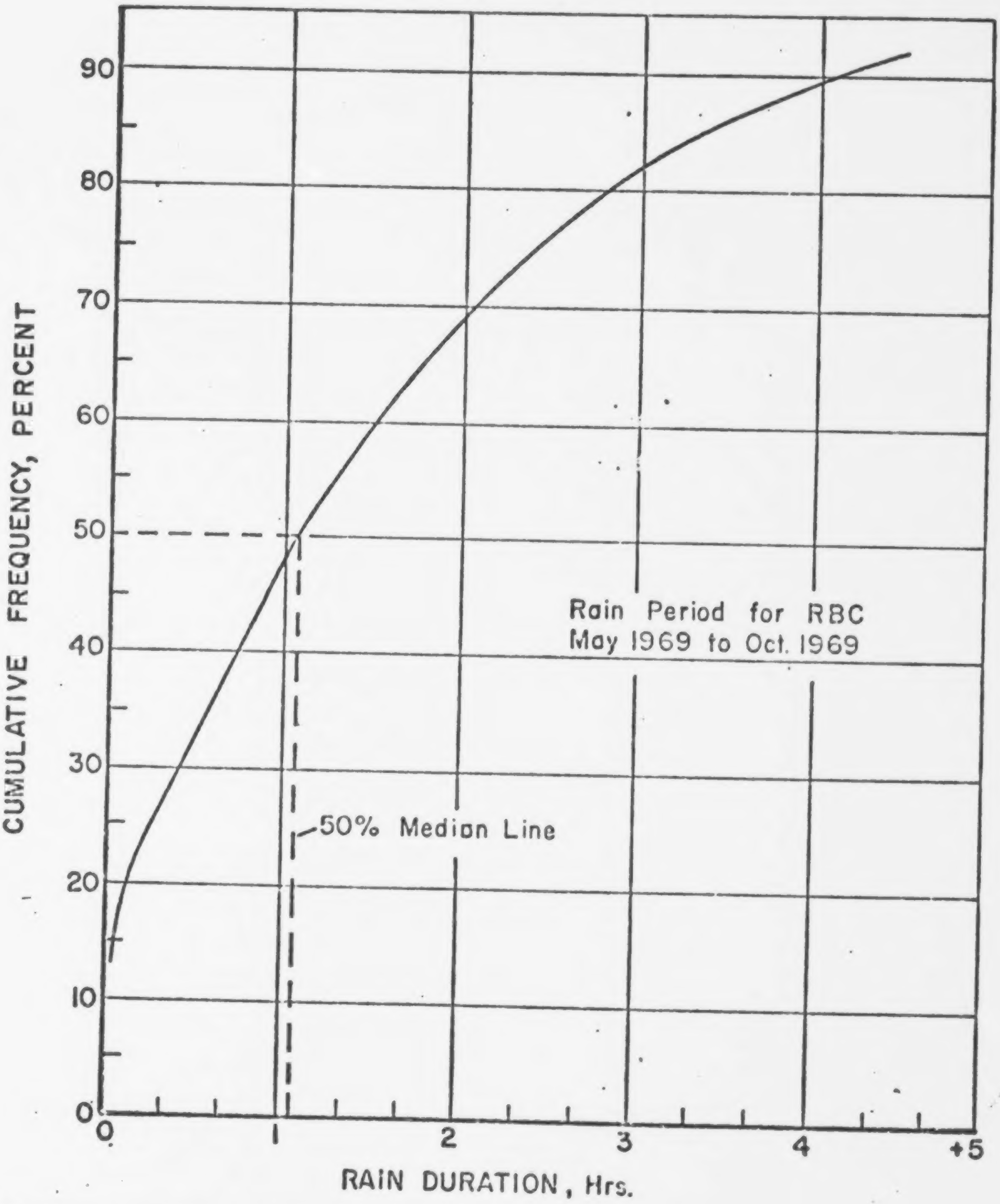
MONTANA STREET PLANT - TOTAL WET WEATHER FLOW FREQUENCY LEVEL

FIGURE 36



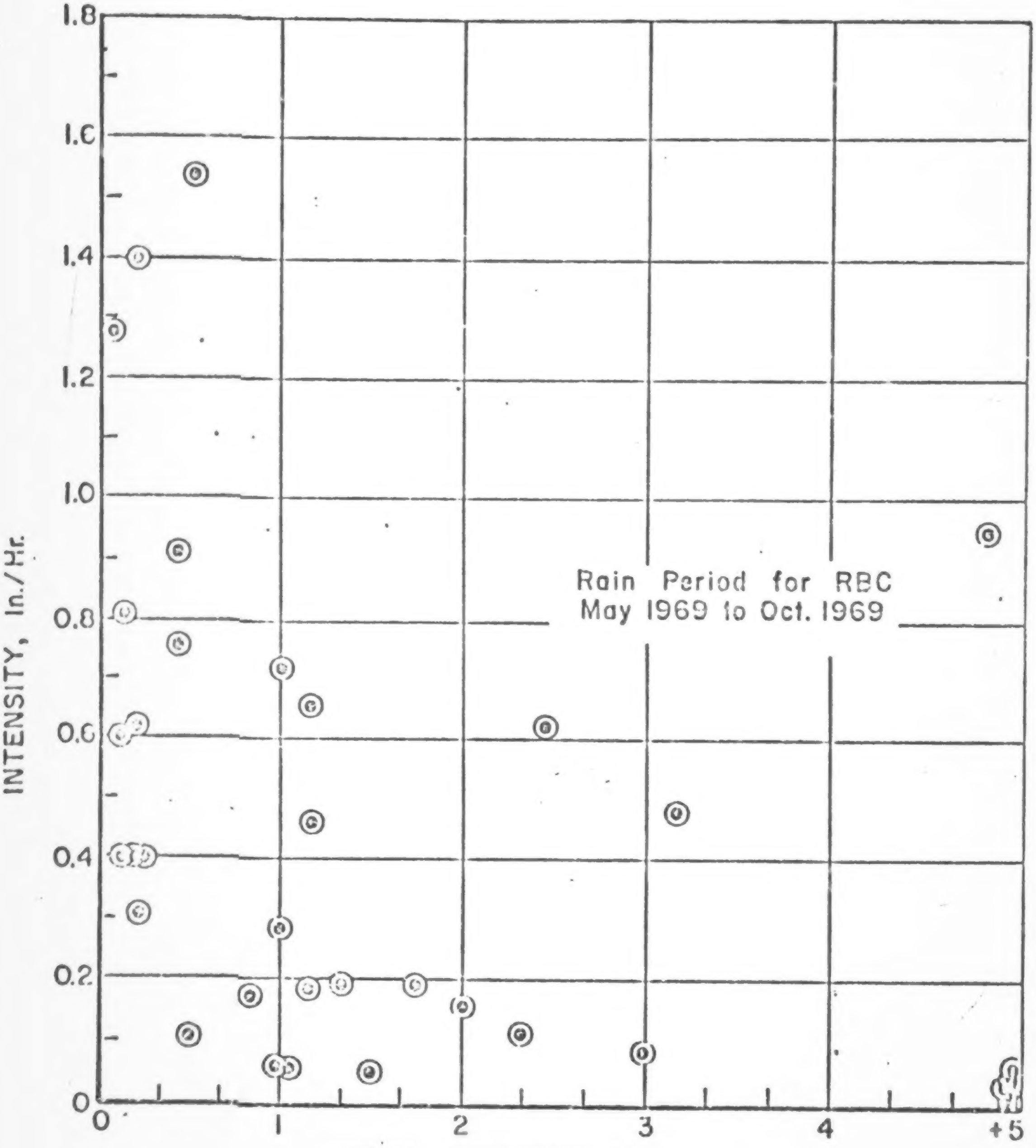
MONTANA STREET PLANT - TOTAL WET WEATHER FLOW FREQUENCY PERCENTAGE

FIGURE 37

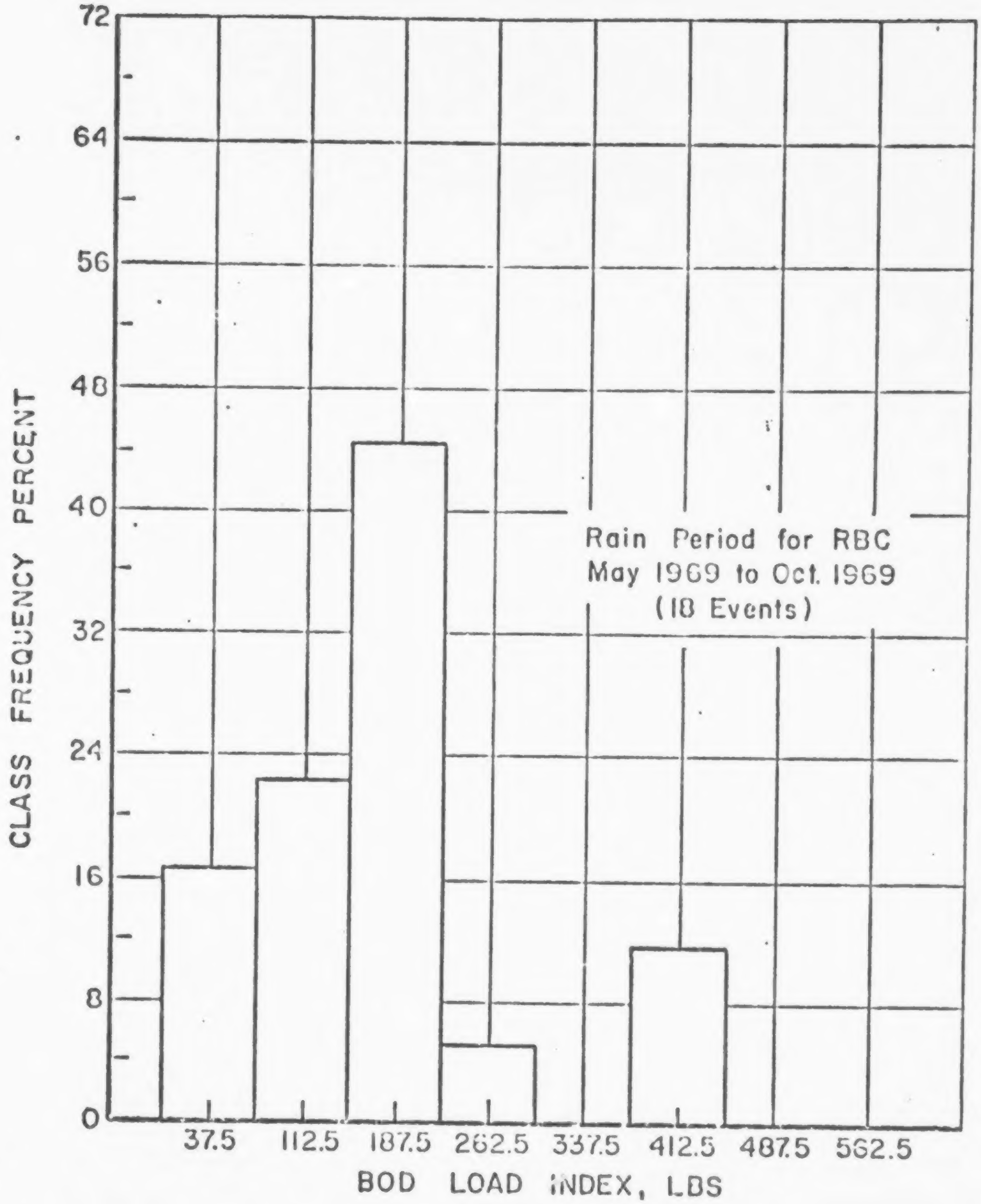


MONTANA STREET PLANT - RAIN DURATION FREQUENCY PERCENTAGE

FIGURE 38



MONTANA STREET PLANT-RAIN INTENSITY vs DURATION-SCATTER DIAGRAM
Figure 39



WET WEATHER ORGANIC-BOD_5-LOAD FREQUENCY

FIGURE 40

Again, as with preceding pilot studies, it was noted that the higher organic loadings tended to occur in the first 5 to 10 minutes of the rain event.

Under normal dry weather flow conditions, total pounds of organic pollutant treated ranges between 100 to 130 pounds per day. Measured rainfall levels would indicate a 150 to 200% increase in the organic treatment level to any biological treatment system.

ORGANIC MEASUREMENT RATIOS

The plot of COD versus BOD load (Figure 41) shows that the influent BOD was 0.64 of the influent COD. This least squares value was not significantly different from determinations on municipal sewage at Jones Island. The COD versus settleable solids ratio of 0.72 was determined for the combined runoff waste (Figure 42).

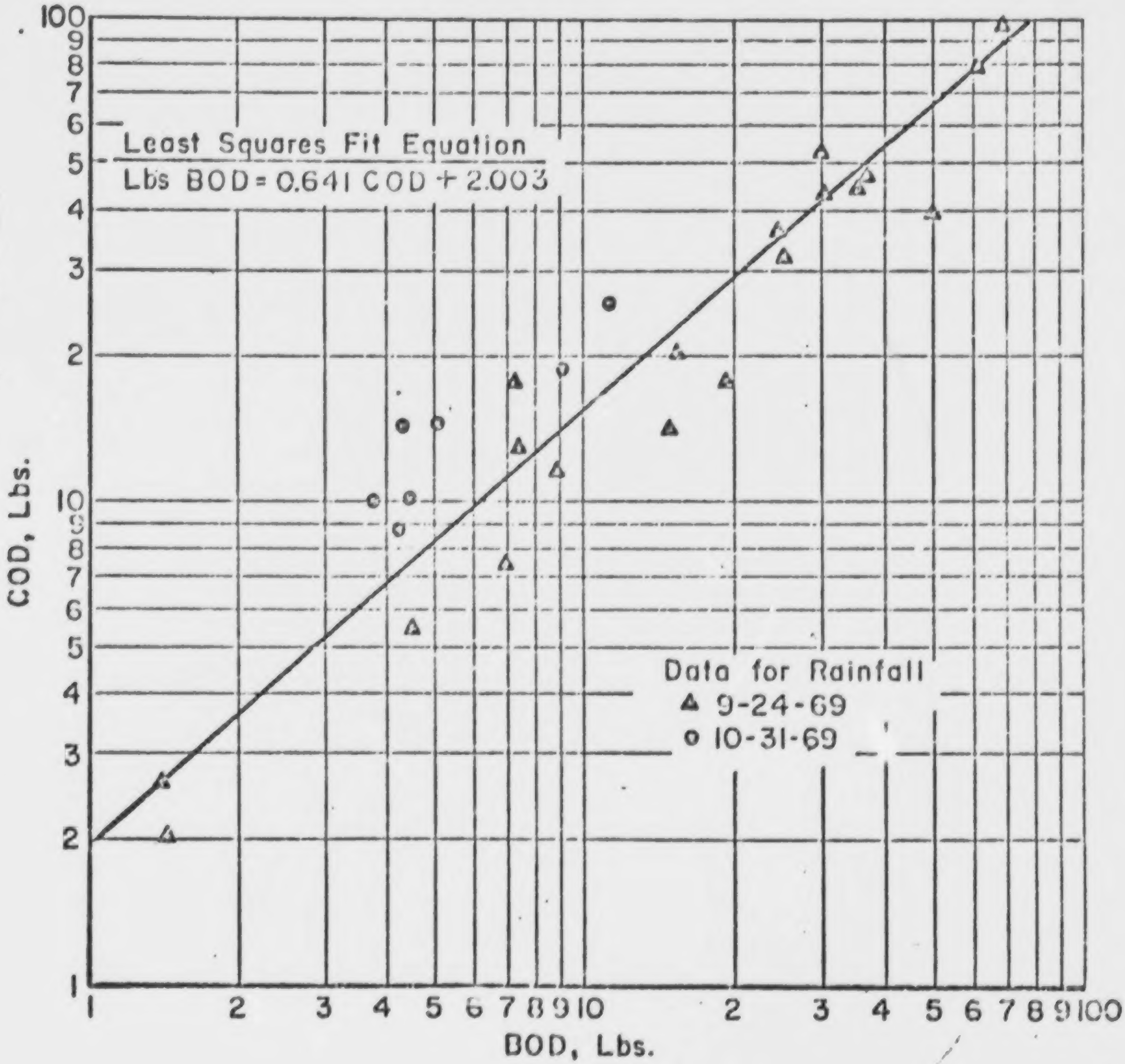
PEAK ORGANIC LOADS

Figures 43 and 44 indicate the time periods at which peak concentrations of COD and BOD pollutants enter the RBC system. BOD and COD data was assumed to have come from a normal population. On the average, 50% to 70% of the organic load, as COD (Figure 43) occurred in 35 to 58 minutes. The longest time for at least 50% of the organic load to occur was 60 minutes. The same equivalent organic load occurred in 46 to 64 minutes.

The difference noted is explainable from the standpoint of the measurements themselves. The COD measurement takes into account not only the more easily biodegradable material, but also the less biodegradable and non-biodegradable materials. The latter two materials are not measured by the BOD analysis. As a result, higher percentages of the organic load are evidenced by the earlier phase of any storm event. This being the case, organic load levels in the RBC system are more representatively depicted by the COD norm rather than BOD_5.

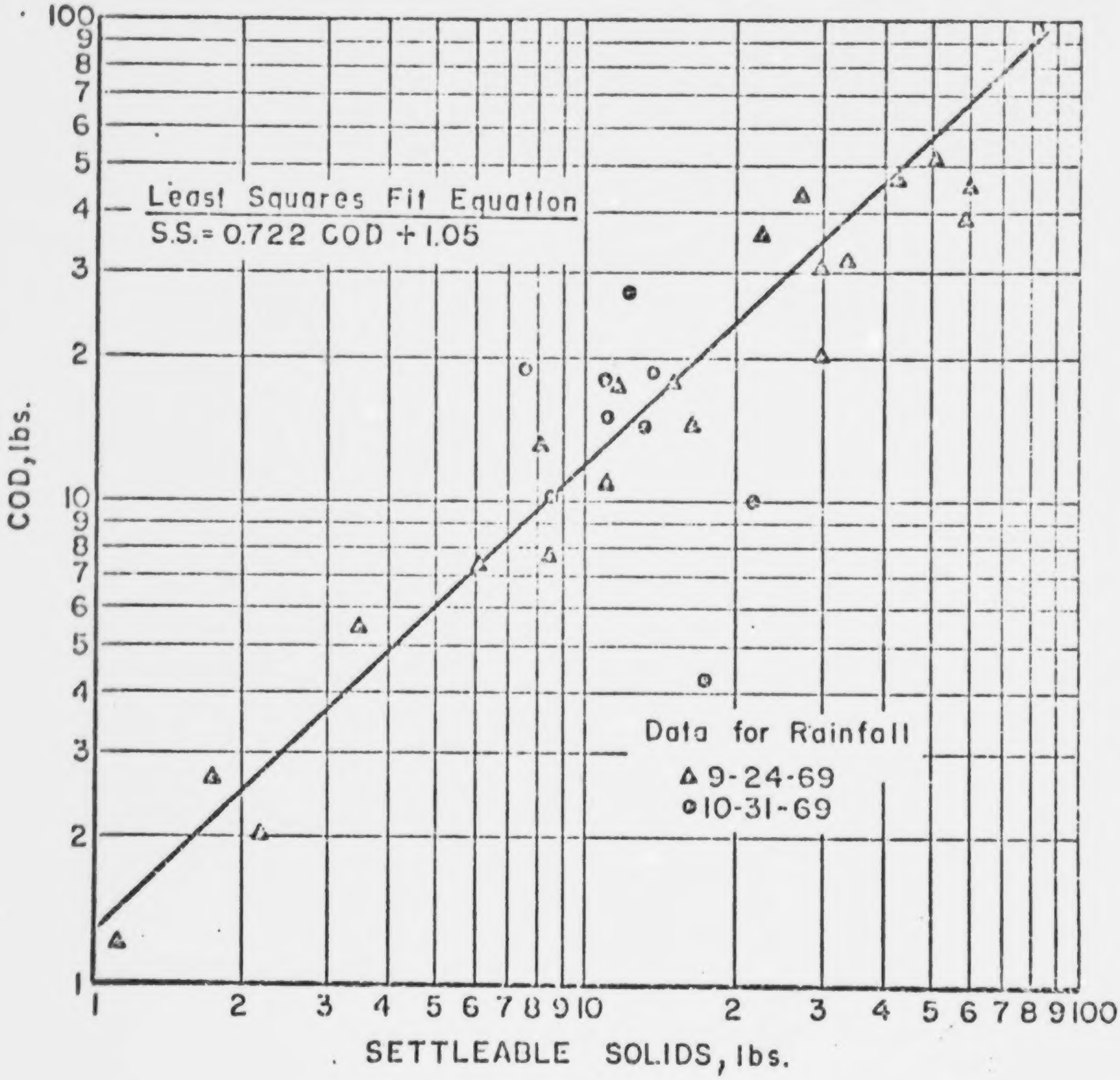
In general, rainfall data can be summarized as follows:

- The maximum hydraulic and organic load levels occurred 5 to 10 minutes after the onset of each rain event. For at least 50% of the rainfall recorded, the volumetric load, in this time span, had a range of 120,000 ± 40,000 gallons. Concurrently, the organic load introduced into the RBC system was 150 lbs. BOD.
- The median rain duration was 1.1 hours, with the shorter rain events (0.1 to 1.1 hours) having the highest runoff intensity with a median rate of 0.56 inches per hour, and the longest ones the lowest intensity at a median rate of 0.10 inches per hour.



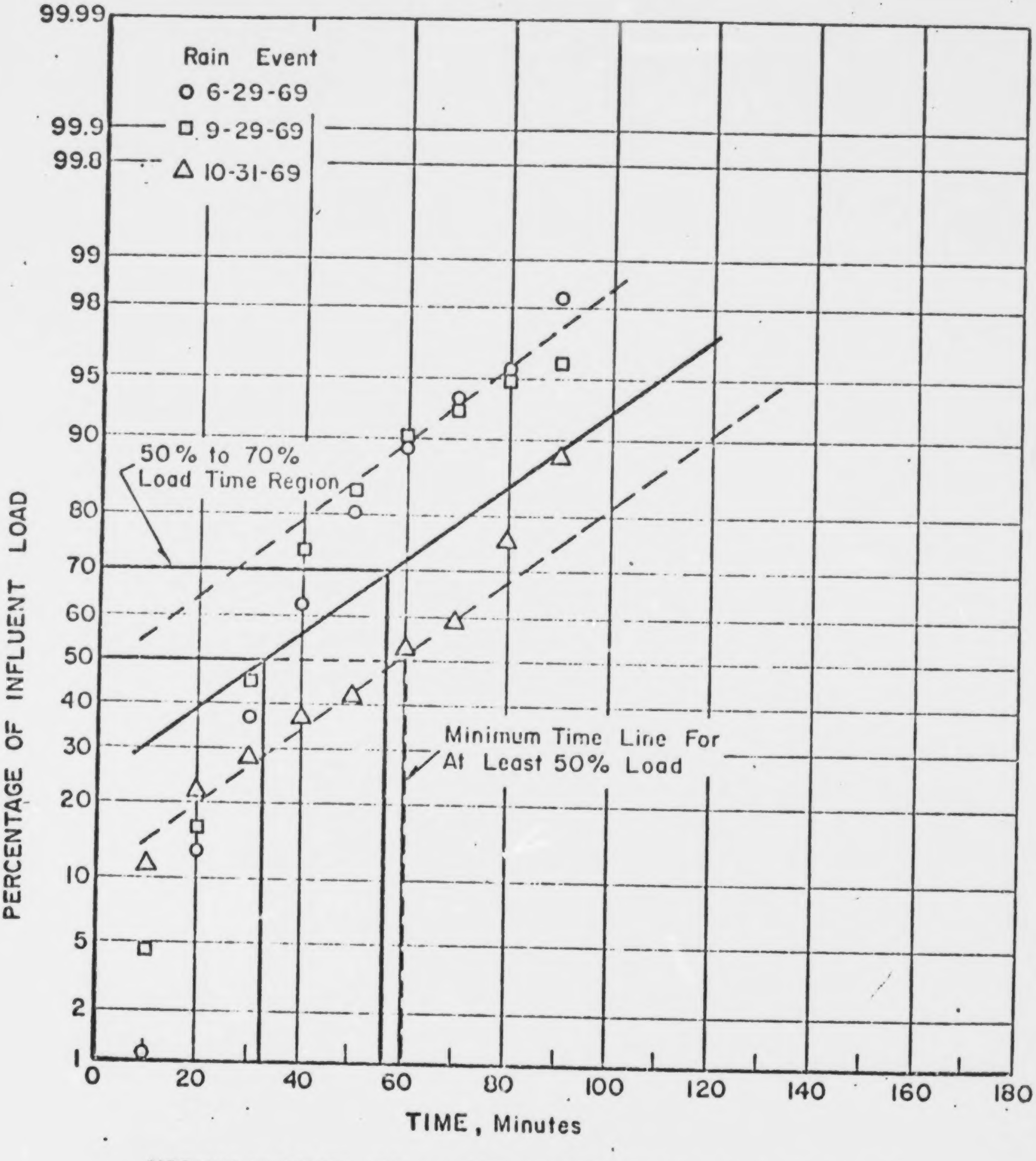
RATIO OF BOD TO COD

FIGURE 41



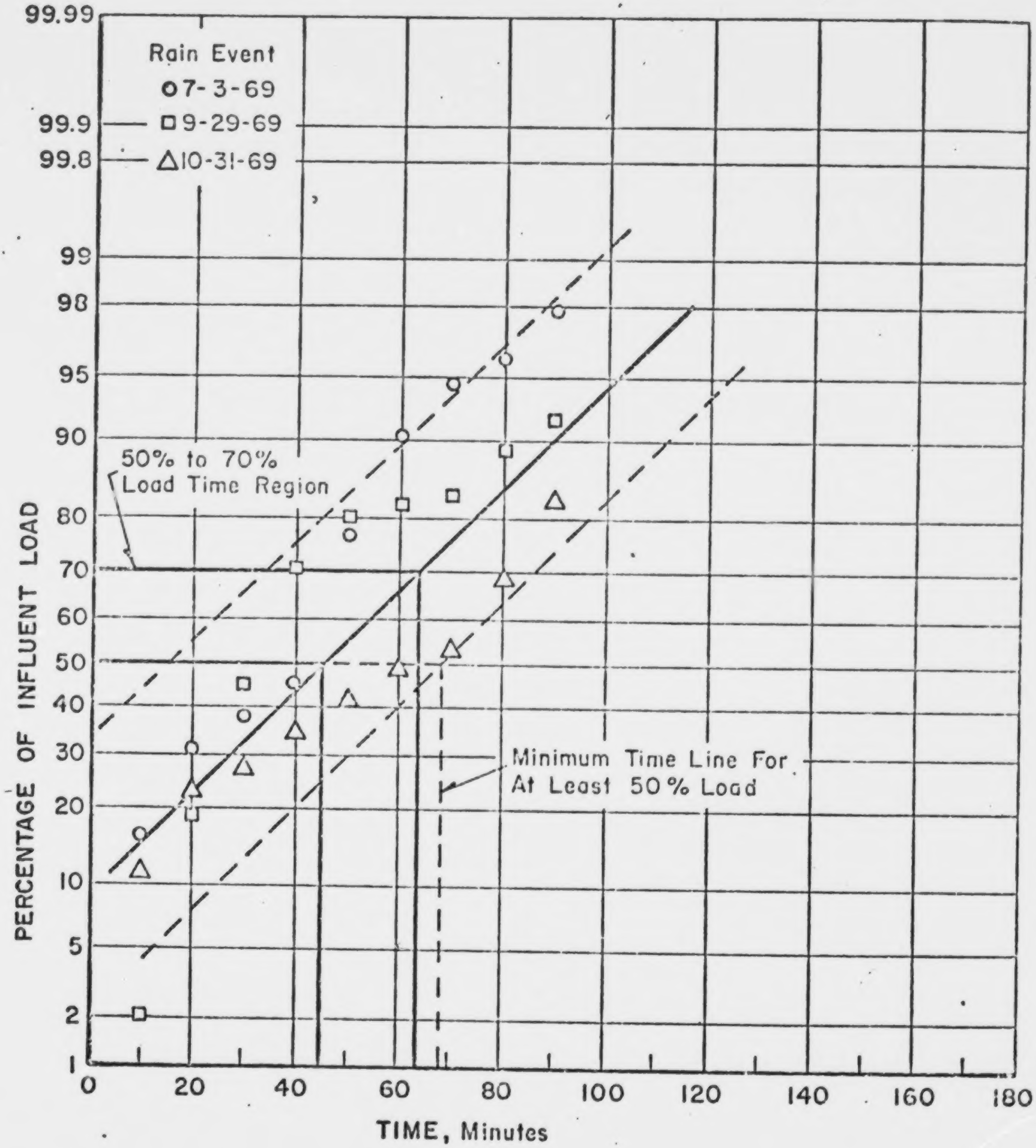
RATIO OF SETTLEABLE SOLIDS TO COD

FIGURE 42



NORMALIZATION OF WASTE WATER ORGANIC LOADS-COD

FIGURE 43



NORMALIZATION OF WASTE WATER ORGANIC LOADS-BOD

FIGURE 44

Average rainfall intensity was 0.46 inches per hour for the demonstration area.

- The median storm flow was 1,500 gpm (43 DWF). Peak rates were experienced up to 3,000 gpm or 86 DWF.

SECTION VII

HYDRAULIC CHARACTERISTICS OF THE DEMONSTRATION PLANT

DRY WEATHER FLOW

Over the test period of the program, the average dry-weather flow was found to be 50,400 gpd (or 35 gpm). This rate was in accordance with the estimated design flow determined in preliminary studies during the design and construction phase. Figure 45 shows the typical hourly variation of the flow for the demonstration site.

Table 7 compares operating parameters of the laboratory units and the demonstration plant during dry weather flow conditions. The COD reductions reported are blended influent values weighed against settled effluent samples. This comparison was selected, because it best represented the organic reducing efficiency of a storm water treatment plant with secondary settling. Levels of incoming settleable solids are presented also; as this constituent, if not controlled in the feed, influences the COD reduction capacity of the RBC system.

Data of Table 7 indicate that the COD reduction has a plant/model ratio of unity between the demonstration plant and the lab model. Slight differences were attributable to variation in organic strength of the waste. Adjusted COD values have historically denoted very nearly the same organic reduction capacity.

FIGURE 45

DRY WEATHER FLOW 8TH. & MONTANA
24 HR. AVG. -34,080 GAL.
4-15-68

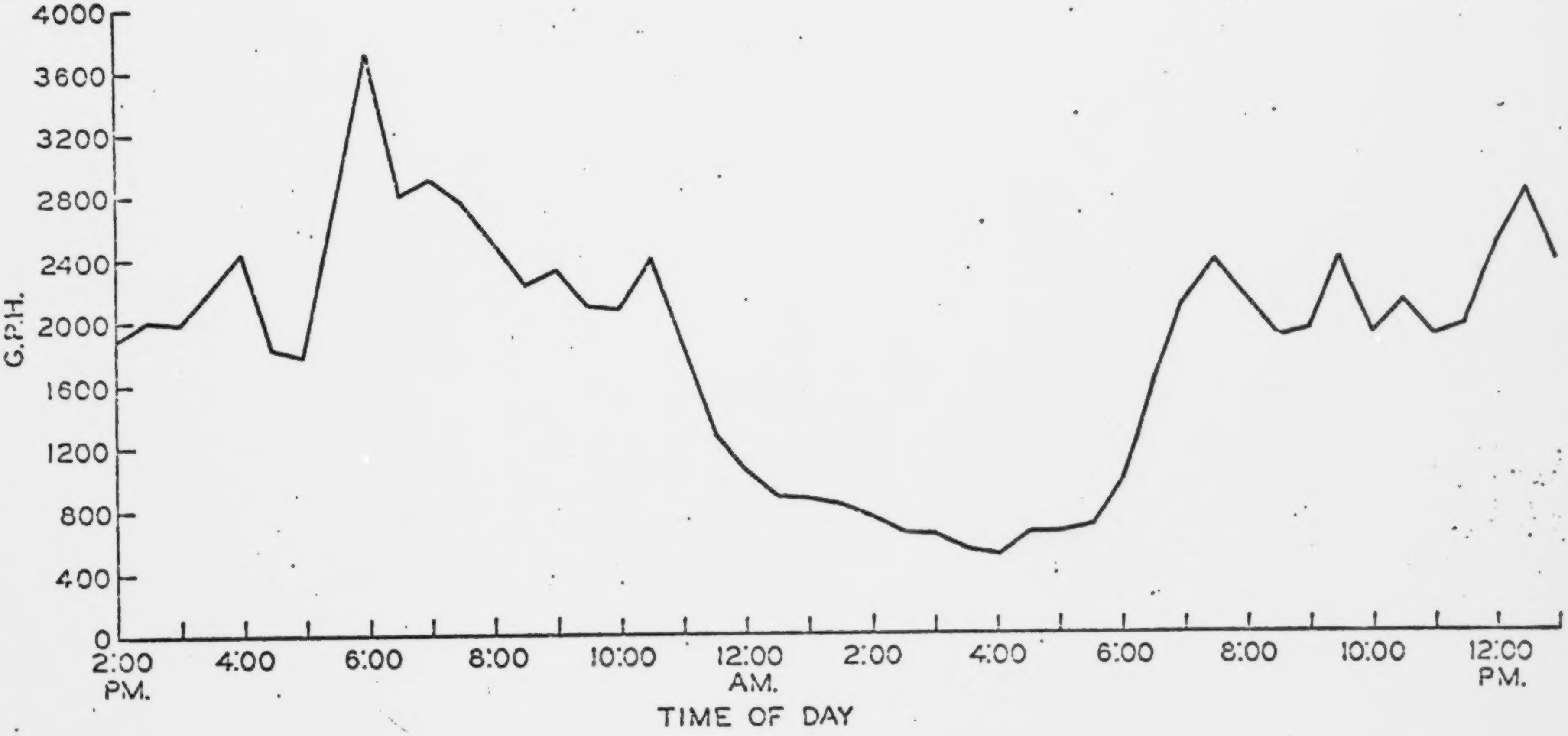


TABLE 7

COMPARATIVE DRY WEATHER FLOW CONDITIONS FOR LABORATORY AND DEMONSTRATION SITES

Parameter	Lab Model[1]	Jones Island	Montana Street	Plant Model Ratio
Average Dry Weather Flow, GPH	60	80	2100	
Retention Time, Minutes	60		69	1.15
		45	69	1.53
Disc Surface Area, Ft^2	504	504	28,300	
Settleable Solids, mg/l	14.8		9.50	0.69
		9.85	9.50	0.96
Raw COD, mg/l[2]	500		361	0.72
		551	361	0.65
Hydraulic Loading Rate, GPD/Ft^2	3.0		1.8	0.60
		3.8	1.8	0.47
Organic Loading Rate, $\frac{\text{Lb. COD}}{1000\ Ft^2}$	12.0		5.4	0.45
		17.6	5.4	0.30
COD Reduction, %	66		76	1.15
		80	76	0.95

---

[1] Data collected with synthetic dairy sewage whereas that for other RBC units used municipal sewage.

[2] BOD/COD ratio averages 0.65 for all three locations.

The plant/model ratio for settleable solids at Jones Island and the demonstration plant was also very nearly unity. Pilot plant results would, in effect, reflect those expected under dry-weather flow conditions at the demonstration site.

HYDRAULIC JET EFFECTS FROM STORM PUMPS

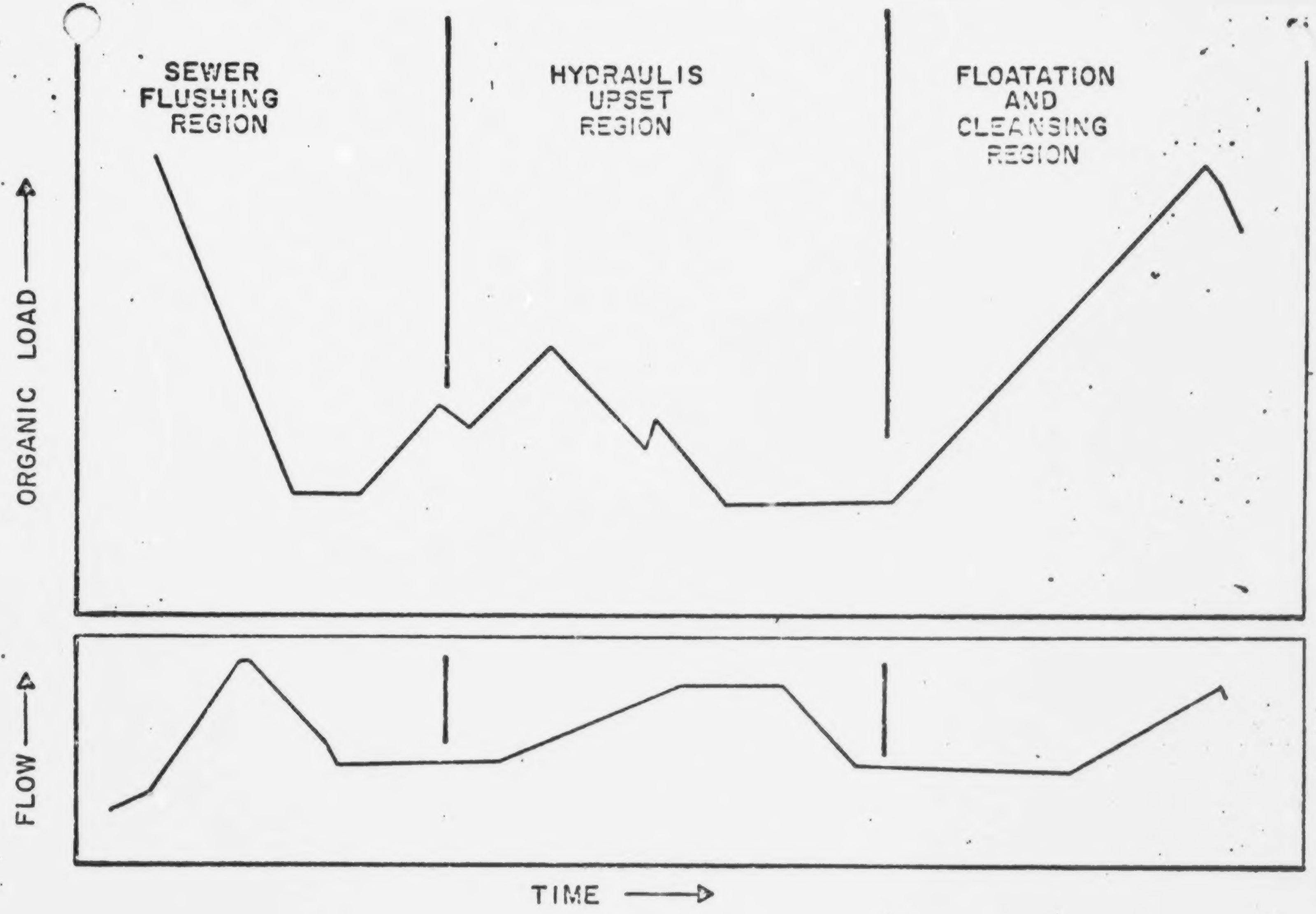
Hydraulic data at the demonstration plant showed that three distinct flow patterns (Figure 46) are associated with pumping of storm water past the RBC discs. These are:

1. Sewer flushing into the RBC plant.
2. Secondary hydraulic surges.
3. Floc flotation and removal of biomass from the RBC system.

These patterns, it was felt, related to the activation of auxiliary storm pumps (See also Section V). When given depths of water accumulated in the pump well, one or both auxiliary storm pump(s) began to pump wastewater in addition to the dry-weather pump. Depending upon the type of rainstorm or rain-runoff (See Appendix E), the hydraulic flow through the RBC system would become 8 to 30 times dry-weather flow. A brief discussion of these patterns follows.

SEWER FLUSHING INTO THE RBC PLANT

This pattern was characterized by a sudden surge in the wastewater flow. At the same time, the RBC displayed a sudden rise in organic removal capacity and settleable solids efficiency. The improved RBC performance was believed to be artificial and due to physical absorption by the biomass



RBC STORM FLOW PROFILE - 8th & MONTANA

FIGURE 46

rather than immediate biochemical degradation.

The rainfall of October 19, 1969, typifies this hydraulic pattern (Figure 47). For this rain event, the hydraulic flow past the discs was nearly constant at 250 gpm Highest organic loads were recorded in the first 5 to 10 minutes and persisted for nearly 40 minutes. Second and third patterns were in evidence after the sewer flushing period.

Highest organic loads were registered in the first 5 to 10 minutes and persisted for nearly 40 minutes. Second and third phases were not measurably in evidence following the subsiding of this phase.

SECONDARY HYDRAULIC SURGES

Secondary hydraulic surges were found to occur some 30 to 60 minutes following the sewer flushing event. Again, as noted previously, the lag time between these surges was dependent on the type of storm event (See Appendix E). The hydraulic rate past the discs ranged between 8 to 20 DWF. High organic and solids levels were also recorded, but tended to be 20 to 30 percent lower than that measured in the sewer flushing event. The rain event of September 29, 1969 typifies this Phase (Figure 48).

FLOC FLOTATION AND REMOVAL OF BIOMASS

Deleterious effects on the RBC biomass, such as washing out and sloughing, prevail in this pattern. Organic removal capacity is low to zero for the RBC, and settleable solids are

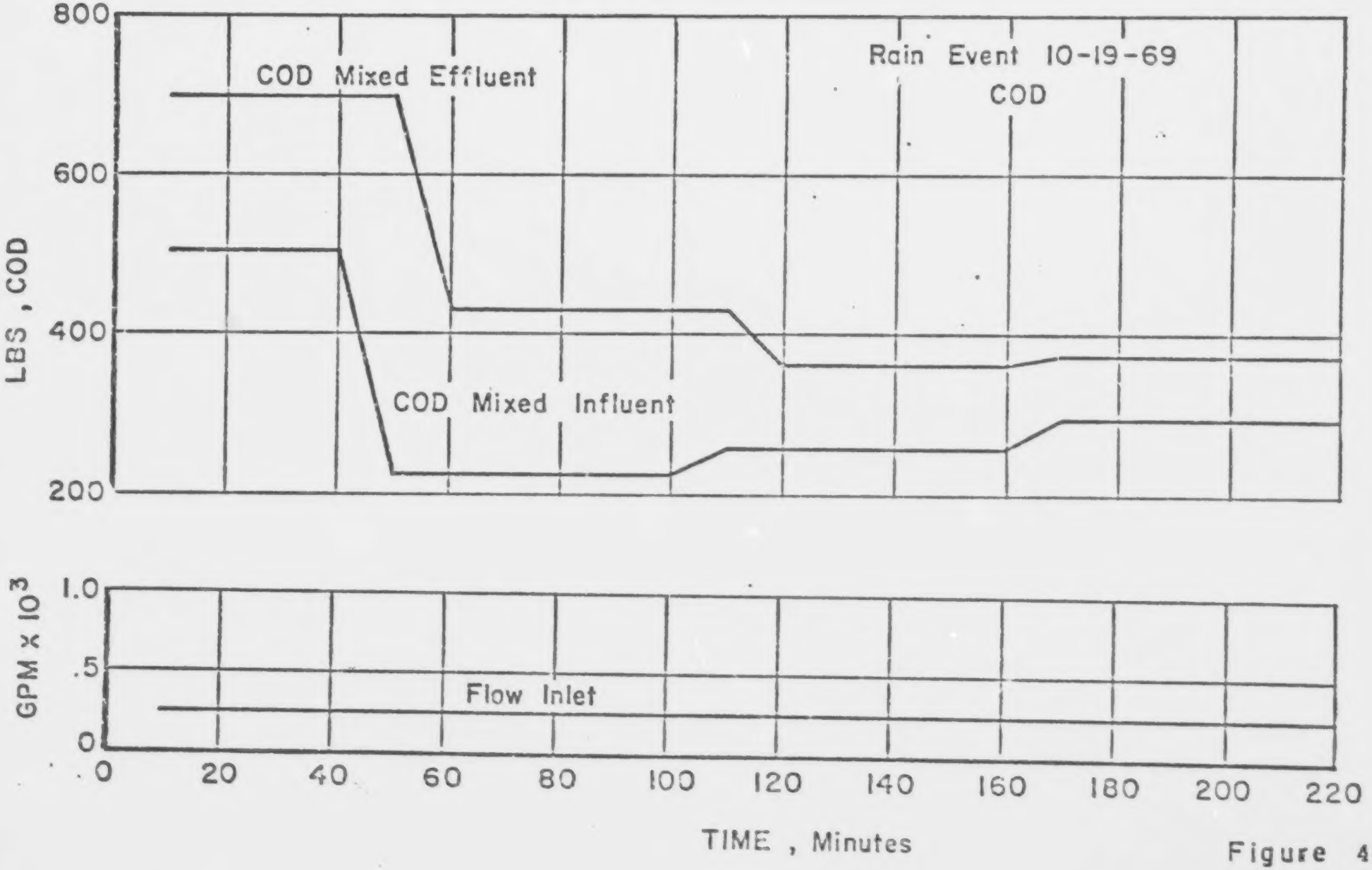

Rain Event 10-19-69
COD
COD Mixed Effluent
COD Mixed Influent
Flow Inlet
LBS , COD
800
600
400
200
GPM x 10^3
1.0
.5
0
0
20
40
60
80
100
120
140
160
180
200
220
TIME , Minutes

Figure 47.

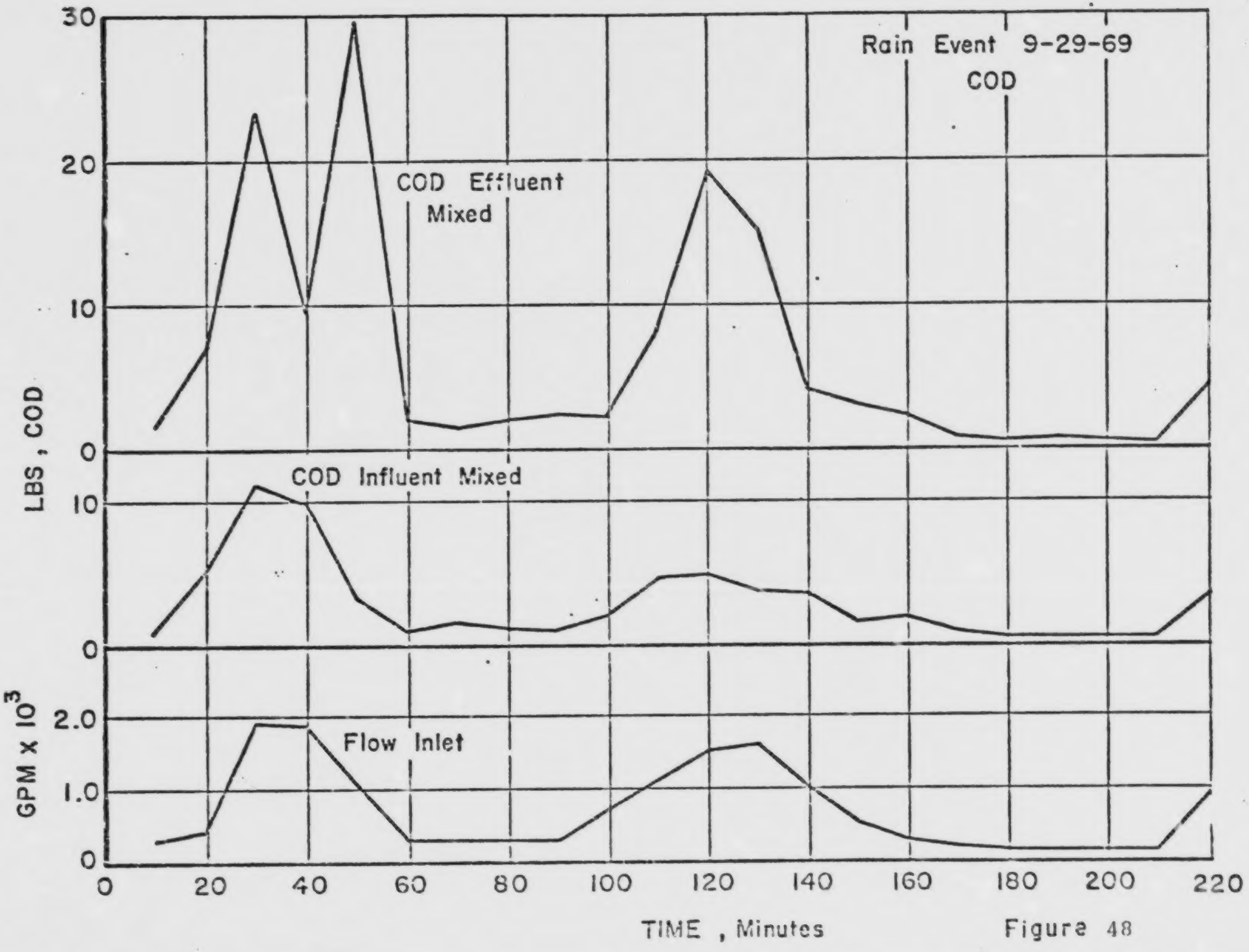

Rain Event 9-29-69
COD
COD Effluent
Mixed
COD Influent Mixed
Flow Inlet
LBS , COD
GPM x 10^3
30
20
10
0
10
0
2.0
1.0
0
0
20
40
60
80
100
120
140
160
180
200
220
TIME , Minutes

Figure 48

markedly reduced.

This pattern is in evidence in the rain event of October 31, 1969 (Figure 49). Storm flow in this example was 20 to 30 times dry weather flow. Influent-effluent settled curves are essentially the same, showing no reduction of dissolved BOD. Mixed effluent BOD, however, is nearly 300% higher than mixed influent BOD. Apparently biomass was leaving the system.

Biomass washout does not necessarily indicate greater sloughing off of floc from the discs. The relative peripheral velocity of the disc rotation to the water is high. Increased wastewater flow through the system did not essentially change the water velocity to disc velocity ratio. As a result, the effects could have been one of flotation of the floc over the weirs and from the submerged screw conveyors.

RBC STORM FLOW PERFORMANCE

Figure 50 shows the influence of storm runoff flow on the COD reduction capacity of the demonstration site. Controlled treatment is shown to be maintained up to 8 to 10 times dry weather flow conditions. At the same time, RBC system effectiveness was shown to decrease sharply as the runoff rate increased.

Effective control of long-duration rainfalls over an extensive period of 6 to 14 hours is illustrated in Figure 51. The average flow measured, in this case, was 14 times dry weather flow (DW

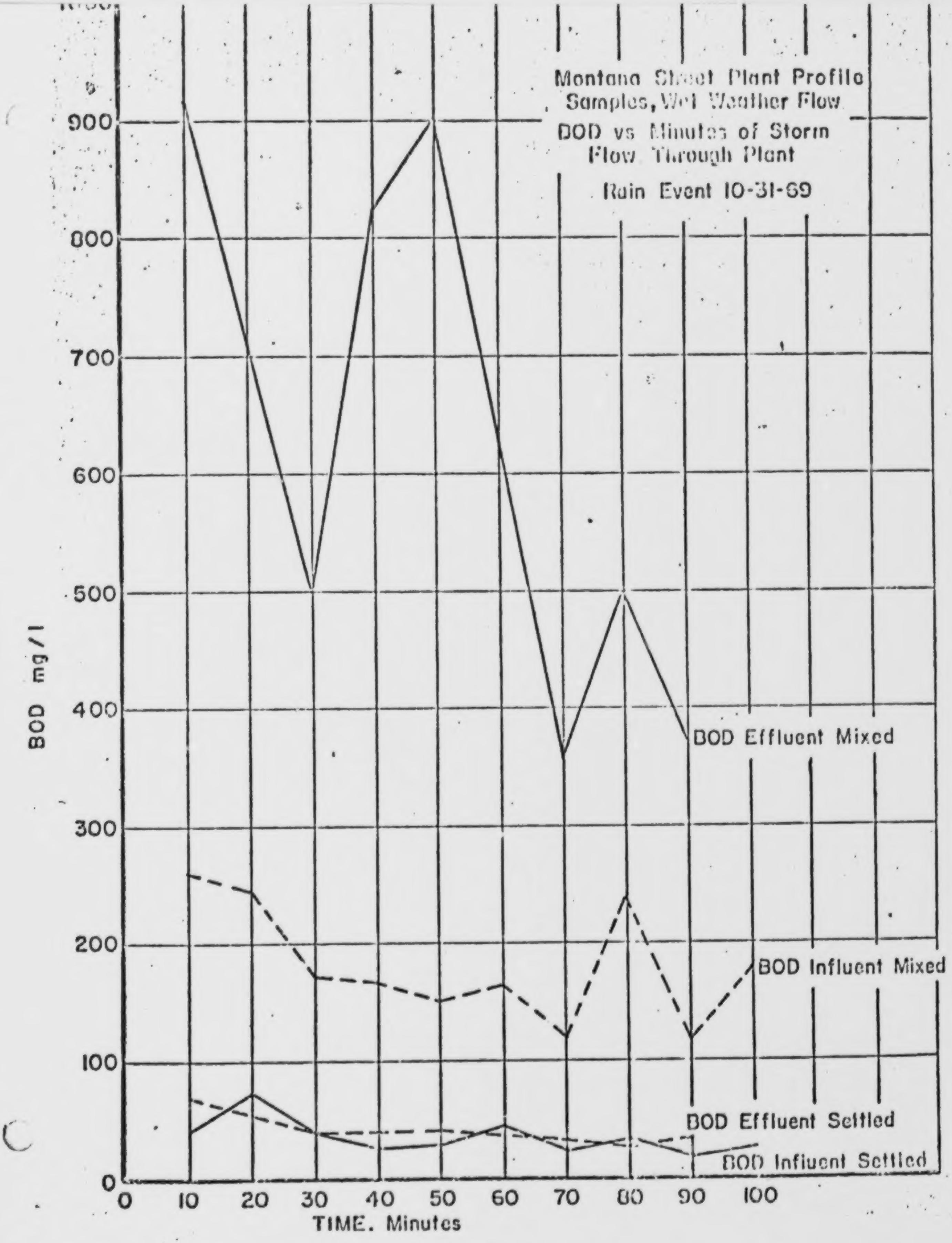


FIGURE 49
WET WEATHER TEST RESULTS

FIGURE 50

STORM RAINFALL PERFORMANCE

OF RBC PROCESS

STORM-RAINFALL PERFORMANCE OF RBC PROCESS

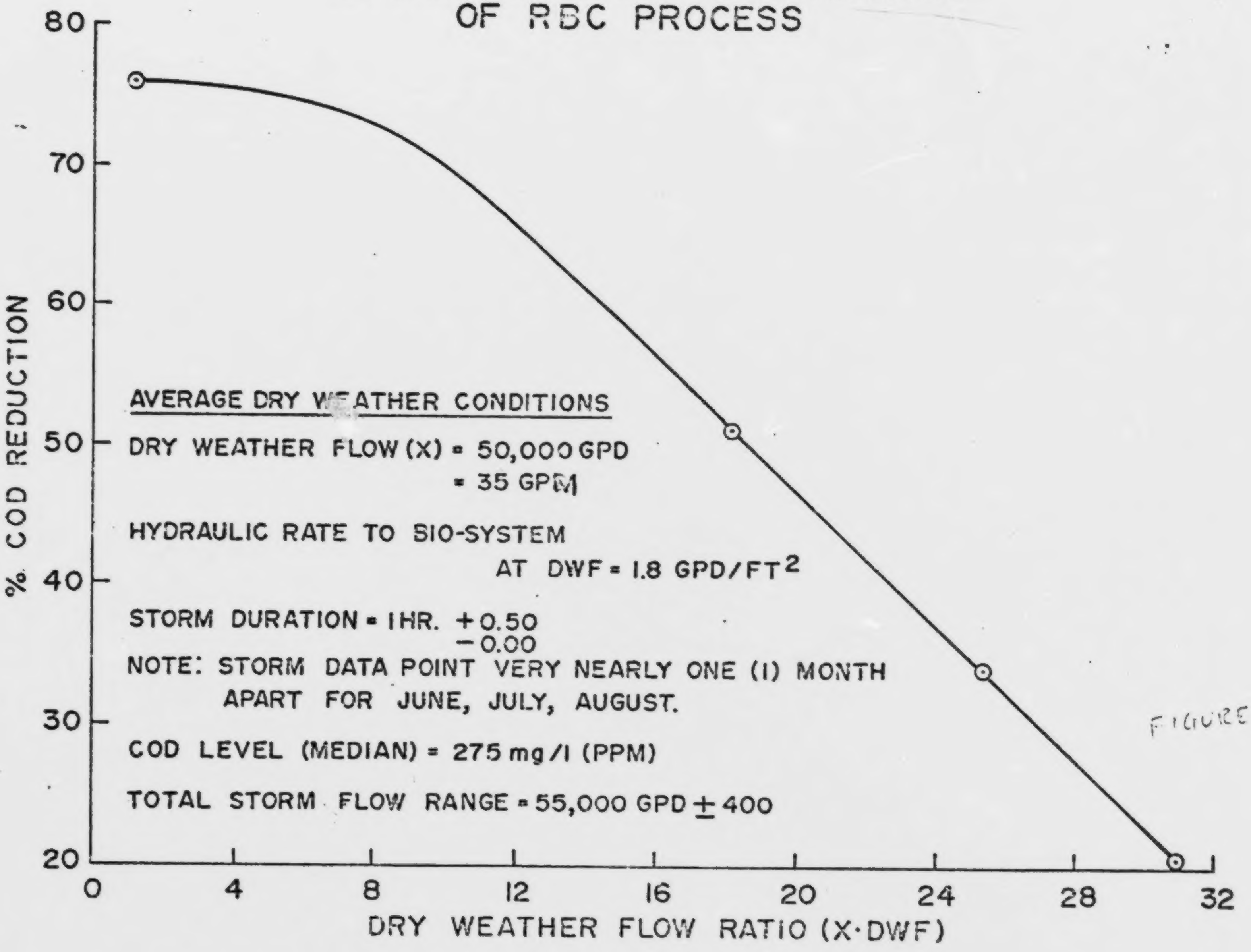
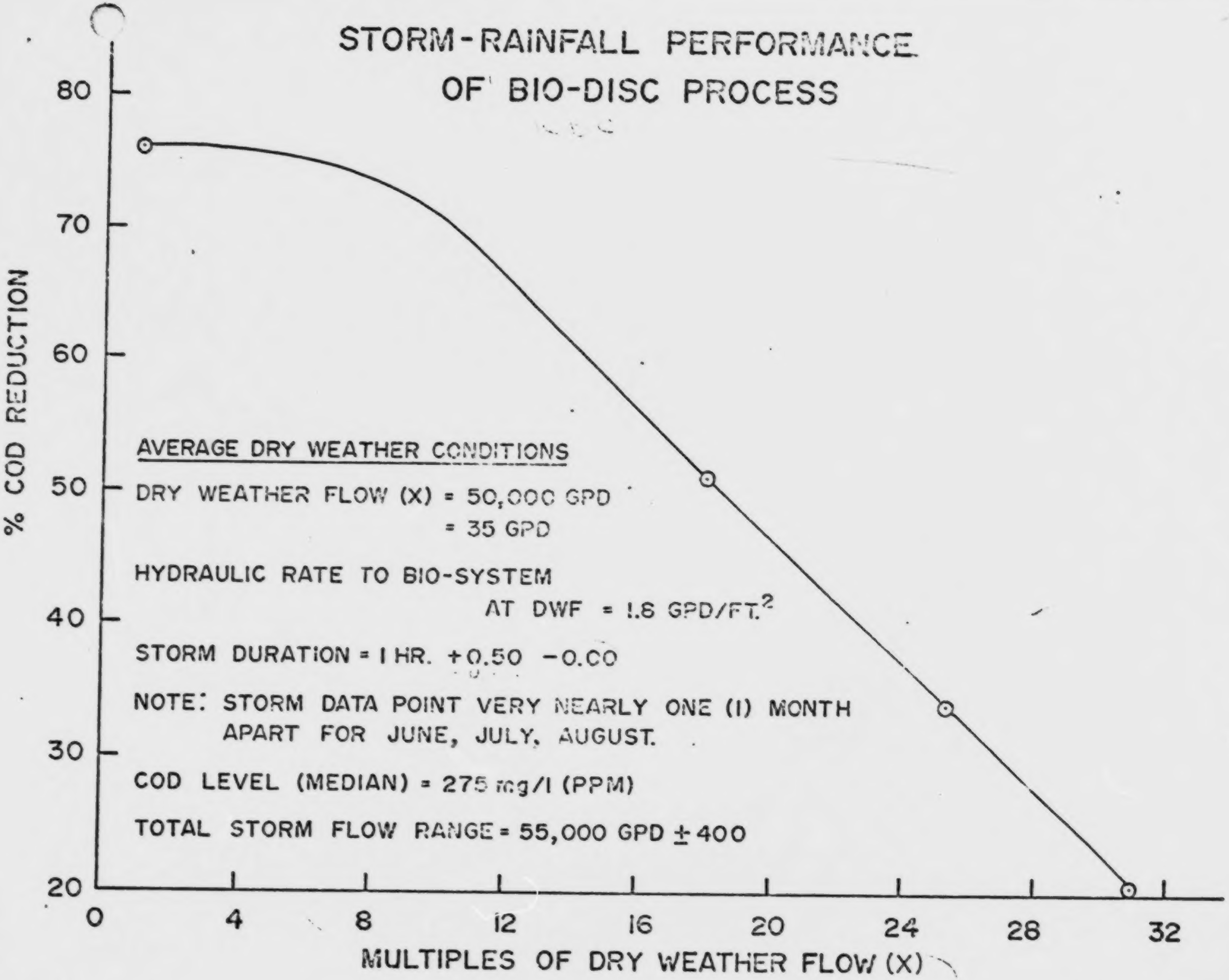


FIGURE 50

9-86.



STORM-RAINFALL PERFORMANCE OF BIO-DISC PROCESS

AVERAGE DRY WEATHER CONDITIONS

DRY WEATHER FLOW (X) = 50,000 GPD
= 35 GPD

HYDRAULIC RATE TO BIO-SYSTEM
AT DWF = 1.8 GPD/FT.^{2}

STORM DURATION = 1 HR. +0.50 −0.00

NOTE: STORM DATA POINT VERY NEARLY ONE (1) MONTH APART FOR JUNE, JULY, AUGUST.

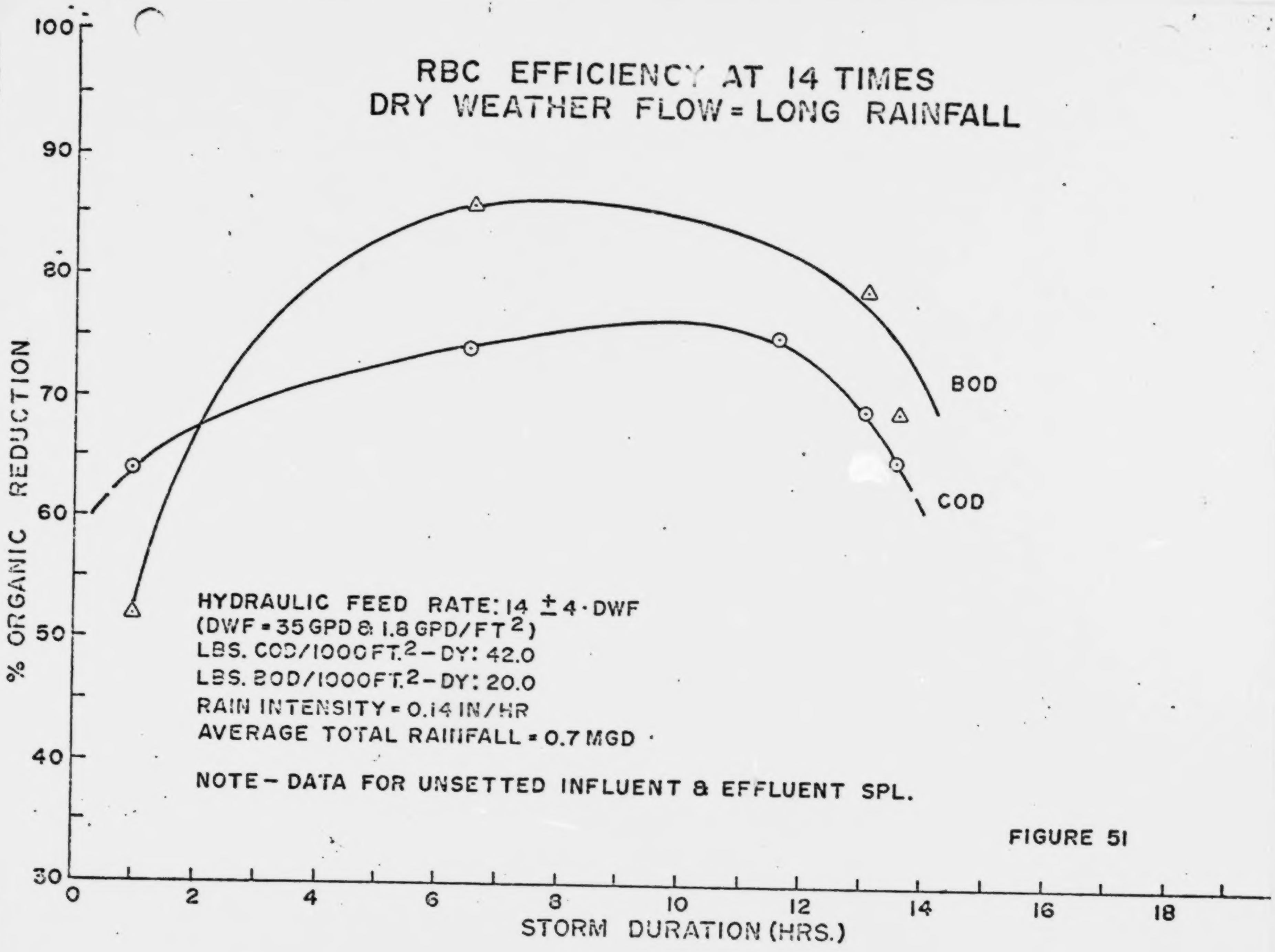
COD LEVEL (MEDIAN) = 275 mg/l (PPM)

TOTAL STORM FLOW RANGE = 55,000 GPD ± 400

FIGURE 51

RBC EFFICIENCY AT 14 TIMES

DRY WEATHER FLOW - LONG RAINFALL



RBC EFFICIENCY AT 14 TIMES
DRY WEATHER FLOW = LONG RAINFALL

HYDRAULIC FEED RATE: 14 ± 4 · DWF
(DWF = 35 GPD & 1.8 GPD/FT^2)
LBS. COD/1000 FT.^{2} – DY: 42.0
LBS. BOD/1000 FT.^{2} – DY: 20.0
RAIN INTENSITY = 0.14 IN/HR
AVERAGE TOTAL RAINFALL = 0.7 MGD

NOTE – DATA FOR UNSETTED INFLUENT & EFFLUENT SPL.

FIGURE 51

Low efficiency levels exhibited in the initial phase of these storms, in most cases, reflected performance at a dilute waste concentration of 150 mg/l or less. Peak performance was achieved after a storm period of 6 to 8 hours, diminishing thereafter in longer storms.

As noted in Figure 52, for storm durations of 10 ± 4 hours, applied loads of 30 ± 15 lbs. COD per 1,000 sq. ft. per day were effectively treated at the demonstration site. Again, the hydraulic flow rate was 14 times dry weather flow. During these periods, the measured rainfall (flow) averaged 0.69 MGD. Rain intensity level was 0.14 inches per hour over the same monitoring time.

The demonstration site was shown to control 80% of the suspended solids level up to loading rates of 28 to 33 lbs./ 1,000 sq. ft. Thereafter, the treatment level asymptotically levels off at 84% suspended solids removal.

RBC RECOVERY PROFILE

Figure 53 shows the hydraulic recovery profile of the RBC system prior to and after several rain events (October, 1969). The data indicates that the return to dry weather flow efficiencies is quite rapid. Depending on the severity of the rainstorm, once the hydraulic upset conditions (greater than 14 DWF) subside, the biological proficiency of the RBC unit progressively improves in 4 to 8 hours. Complete recovery is achieved in 24 hours.

FIGURE 52

STORM LOADING EFFECTS
ON
RBC PERFORMANCE

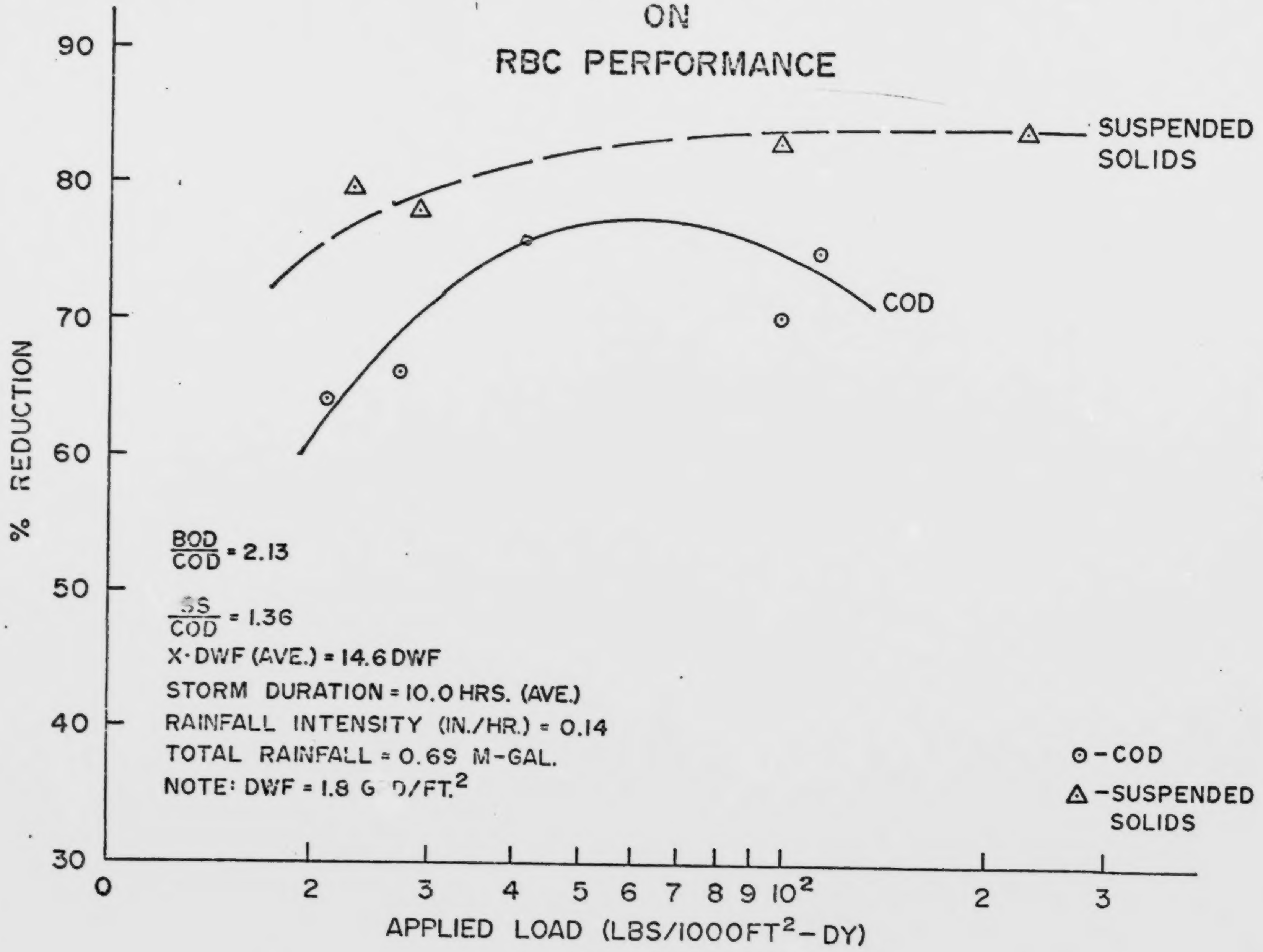


FIGURE 53

SYSTEM RECOVERY PROFILE
AS A FUNCTION OF COD LOADING

SYSTEM RECOVERY PROFILE AS A FUNCTION OF COD LOADING

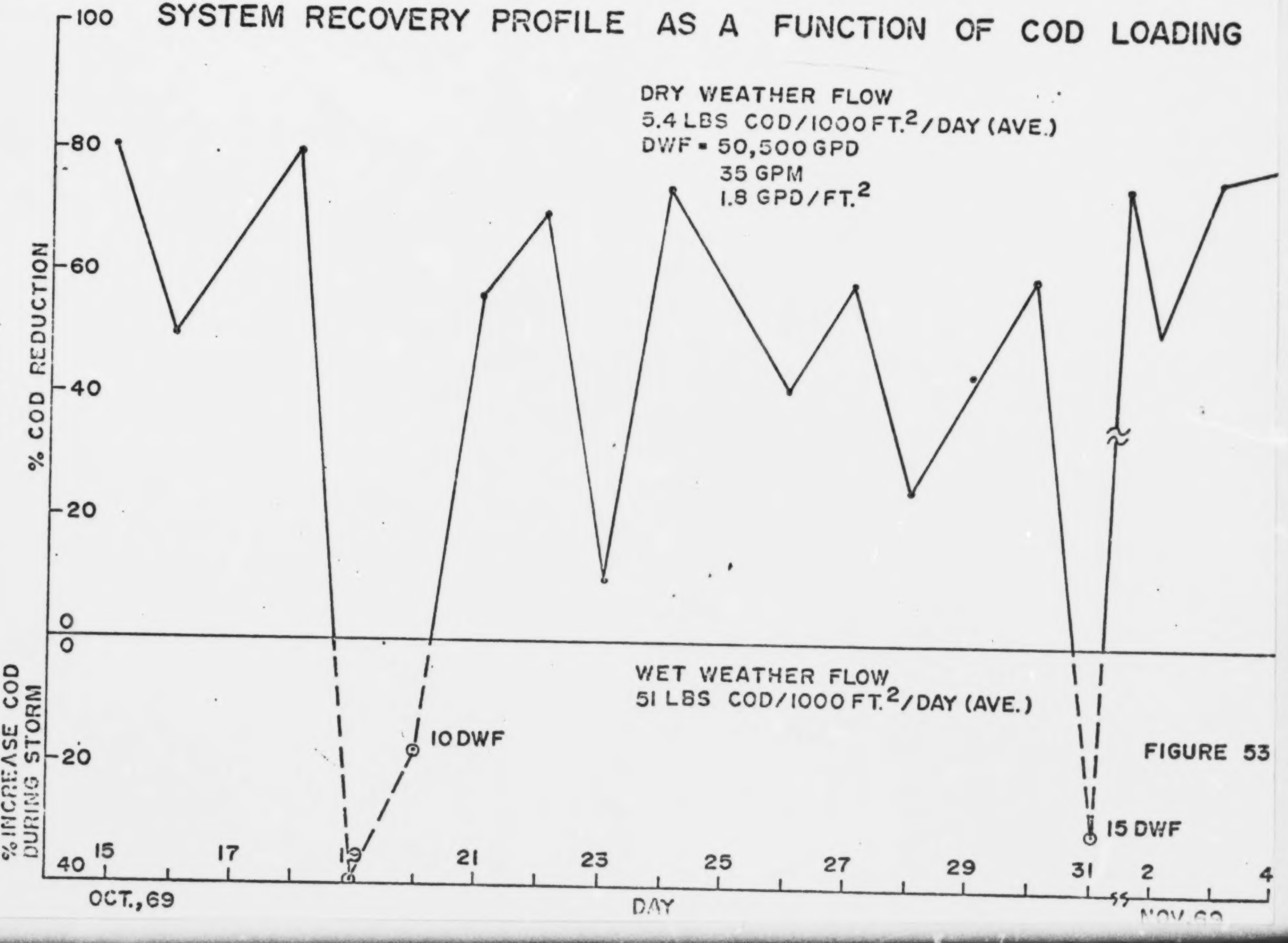


FIGURE 53

In addition to the RBC hydraulic recovery phase, test data also indicate a cyclic biological phase of RBC performance. Depending on the time of day samples were taken, COD reduction data differed by as much as 50% over a 48 to 60-hour span. Dry weather flow data from Jones Island also exhibited this biological lawn periodicity. In this case, the BOD asymptotically approached a limiting biological control level. This biological cycle spans a period of 48 to 120 hours. Greater in-depth evaluation of this biological phenomena was felt to be beyond the scope of this program.

COMPARATIVE RAIN RUNOFF PERFORMANCE

Figure 54 compares the performance of the demonstration RBC in wet weather to the simulated rainfall performance of the pilot plant unit. In the hydraulic range of 8 to 14 DWF, both RBC systems were controlling. Organic concentration levels of the pilot plants, however, were higher at 350 ± 150 mg/l BOD. Under actual field conditions, the organic concentration of the demonstration plant was 150 ± 50 mg/l in the dilute domestic waste range.

Figure 55 compares the effects of storm flow in terms of organic loading rate on pilot plant and demonstration RBC systems. Comparable results are shown to occur at the loading rate of 30 lbs. COD/1,000 sq. ft. per day. RBC efficiency at this level was 73% COD reduction. The demonstration plant exhibited greater biological control

FIGURE 54

EFFECTS OF RESIDENCE TIME
ON RBC COD REDUCTION

EFFECTS OF RESIDENCE TIME ON RBC COD REDUCTION

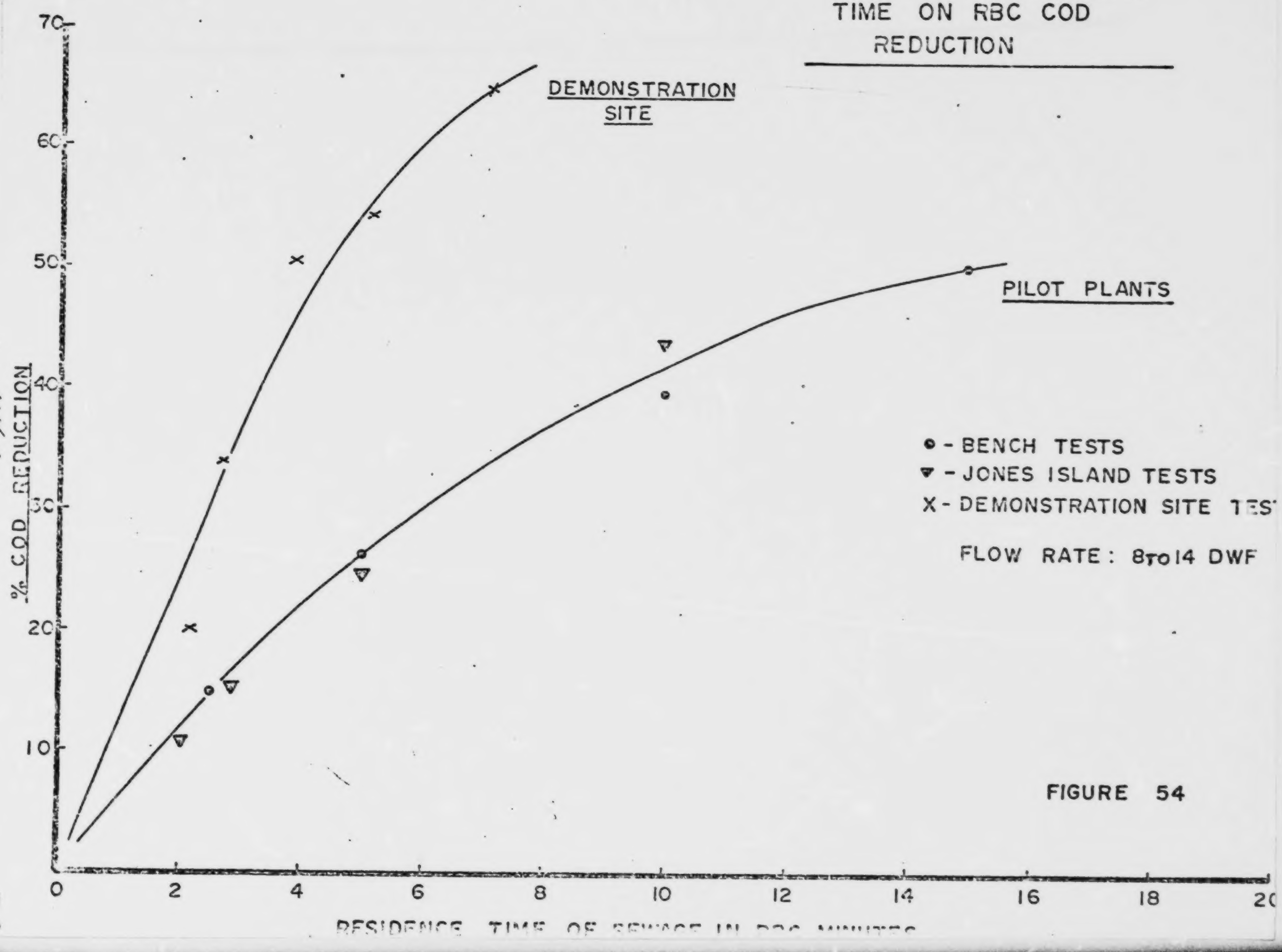
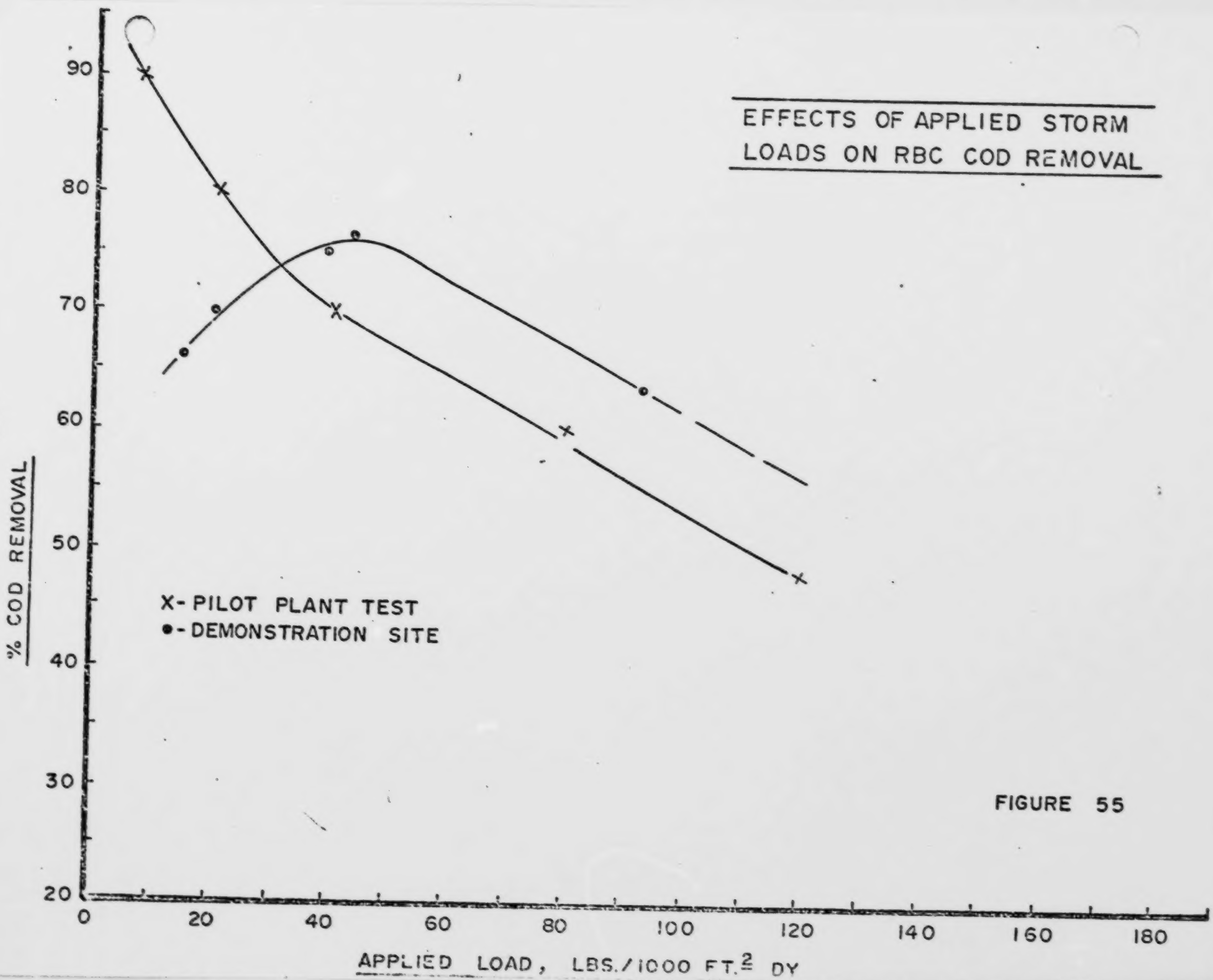


FIGURE 54

FIGURE 55

EFFECTS OF APPLIED STORM LOADS
ON RBC COD REMOVAL



EFFECTS OF APPLIED STORM LOADS ON RBC COD REMOVAL

FIGURE 55

over the applied loading range of 33 to 67 lbs. COD/1,000 sq. ft./day. Unit efficiency in this region was shown to be 74%, and that for the pilot units averaged about 60%.

In summary, RBC performance at the demonstration site not only confirmed pilot plant results, but displayed an ability to handle organic loads at higher levels than those evaluated in the pilot programs. Whereas pilot plant units were able to demonstrate RBC control of storm waste for 15 to 20 minutes at 8 to 10 times dry weather flow, the demonstration unit exhibited a capability to effectively handle storm flows of 14 to 20 times DWF for periods of 8 to 10 hours.

SECTION VIII

IMPROVED ABATEMENT MEASURES

USE OF SETTLING EQUIPMENT

Storm information from the test program indicated that RBC treatment of combined runoff waste could be enhanced by the use of settling equipment. Quantitative evaluations were made with tilted-plate separators of the type shown in Figure 56. Compactness and unit packaging were of prime consideration in its selection. The geometric design of these units minimize the prime concern of being solely dependent on time dependent gravity settling of mixed liquor solids.

Insufficient time and scarcity of rain events hampered detailed study of the benefits to be derived from the equipment. However, some determinations were achieved in the months of November, 1969, and January, 1970 (See Appendix G). The average settleable solids level into this tube settler was 13.0 ml per liter. The average effluent settleable solids was 3.7 ml per liter. A readily separable quantity of 9.3 ml per liter was removed from the final effluent. Data, thus, suggested a favorable benefit was to be obtained in the utilization of settling equipment and should be considered in the design of future RBC storm systems.

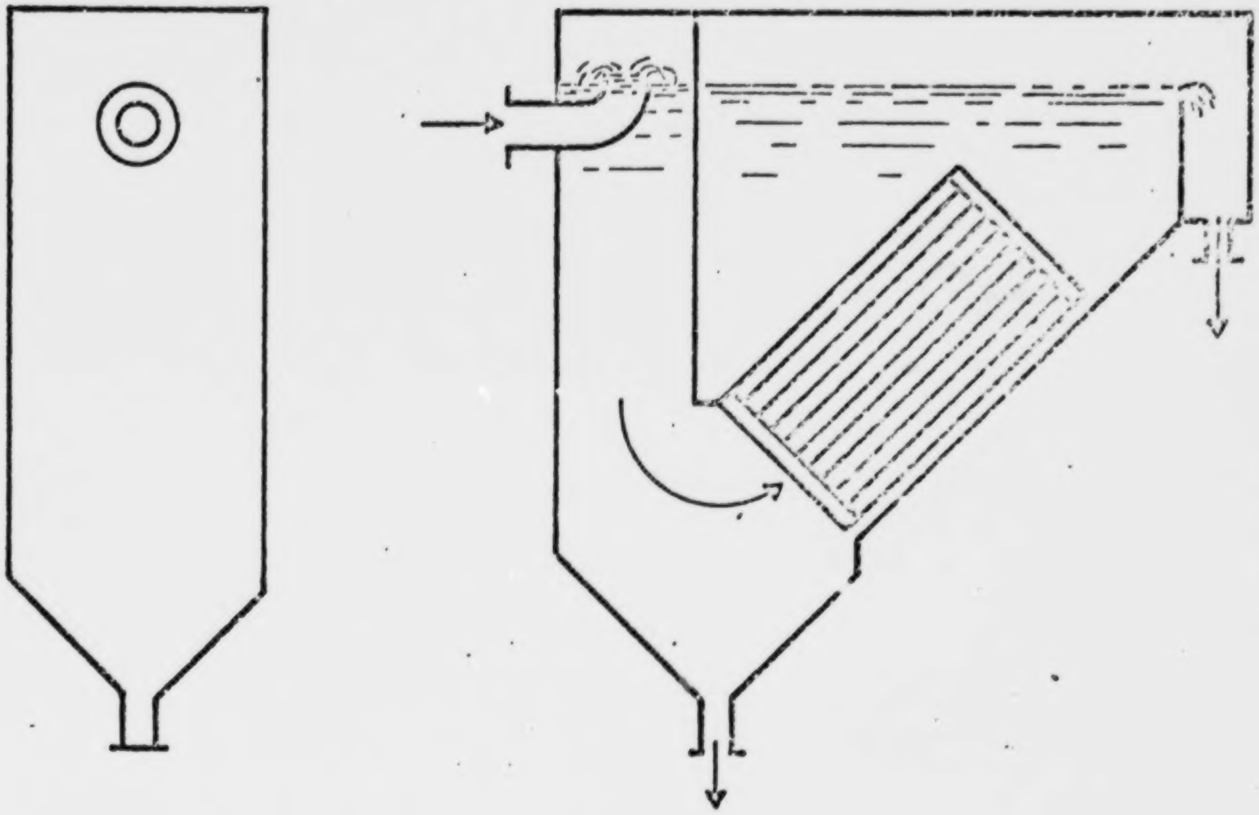


FIGURE 56. TILTED-PLATE SEPARATOR

PEAK SHAVING OF STORM RUNOFF FLOW

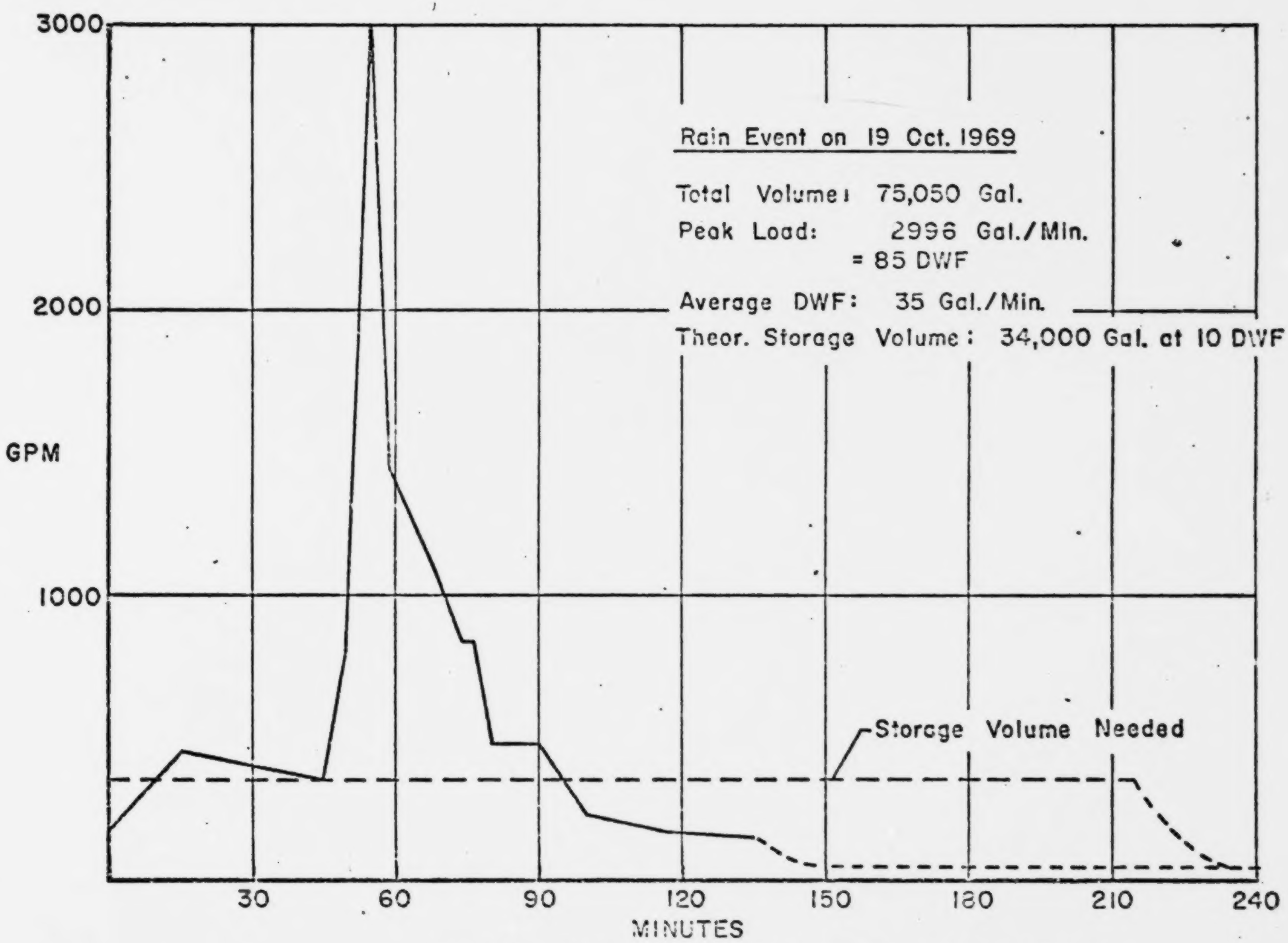
GENERAL

As shown by the data, the RBC exhibited operating stability up to 14 times dry weather flow (DWF = 35 gpm). At flows of 20 to 30 DWF, RBC control diminished readily. More than half the rain events had flows of duration greater than 1.1 hours with a storm runoff rate of 1500 gpm. Total volume represented by these rains was 120,000 ± 40,000 gallons. Thus, control of peak storm flow into the demonstration plant tended to be the essential design parameter of any RBC system.

EXTERNAL PEAK SHAVING STORAGE

An example of storm peak shaving by external storage is illustrated using the rain event of 19 October 1969. Figure 57 shows how a theoretical storage volume, based on 10 DWF, would affect controlled flow to the RBC. The solid line represents the flow rate into the demonstration plant at any given time. The peak flow, 85 DWF, occurred near the 55th minute of the storm; such a high flow rate would undoubtedly wash some biomass from the RBC. The dashed line represents the total storage volume required to limit storm runoff to 350 or 10 DWF.

Again, as illustrated in Figure 57, the controlled storm flow rate is not exceeded in the first ten minutes. The potential storage capacity would not be used at this point, but would be available.



TYPICAL DIAGRAM FOR RAIN EVENT PEAK SHAVING

FIGURE 57

At the 12th minute, the flow exceeds 10 DWF at which point all flow greater than this rate would be channelled to external storage facilities. Peak shaving of this rain event would store nearly 1200 gallons of storm water until the 45th minute of the storm. (This volume is represented on the graph by the area of the triangle between the solid and dashed lines at 12 to 45 minutes). From this period of peak flow to the 95th minute, most of the storm runoff would be stored. Total volume stored would have been nearly 75,000 gallons. Thereafter, the stored water would be emptied gradually into the RBC, maintaining 350 gpm into the RBC until no more wastewater remained in storage.

An adequate storage volume for such rain events would be 100,000 gallons. Volumetric capacity would thus provide storage for at least 50% of the rain events. Even in a rain event, too large to be stored entirely, the portion of high organic load would be stored for later RBC treatment. Ideally, this storage volume would also provide at minimum a storage retention time of 60 minutes or the median storm endurance period.

To control these tremendous hydraulic surges to the RBC system, an external storage facility could be designed very similar to that of Figure 58. This approach would entail the installation of a 100,000 gallon rubber bag along with a head box to provide a constant head for the valve that would control the flow to the RBC.

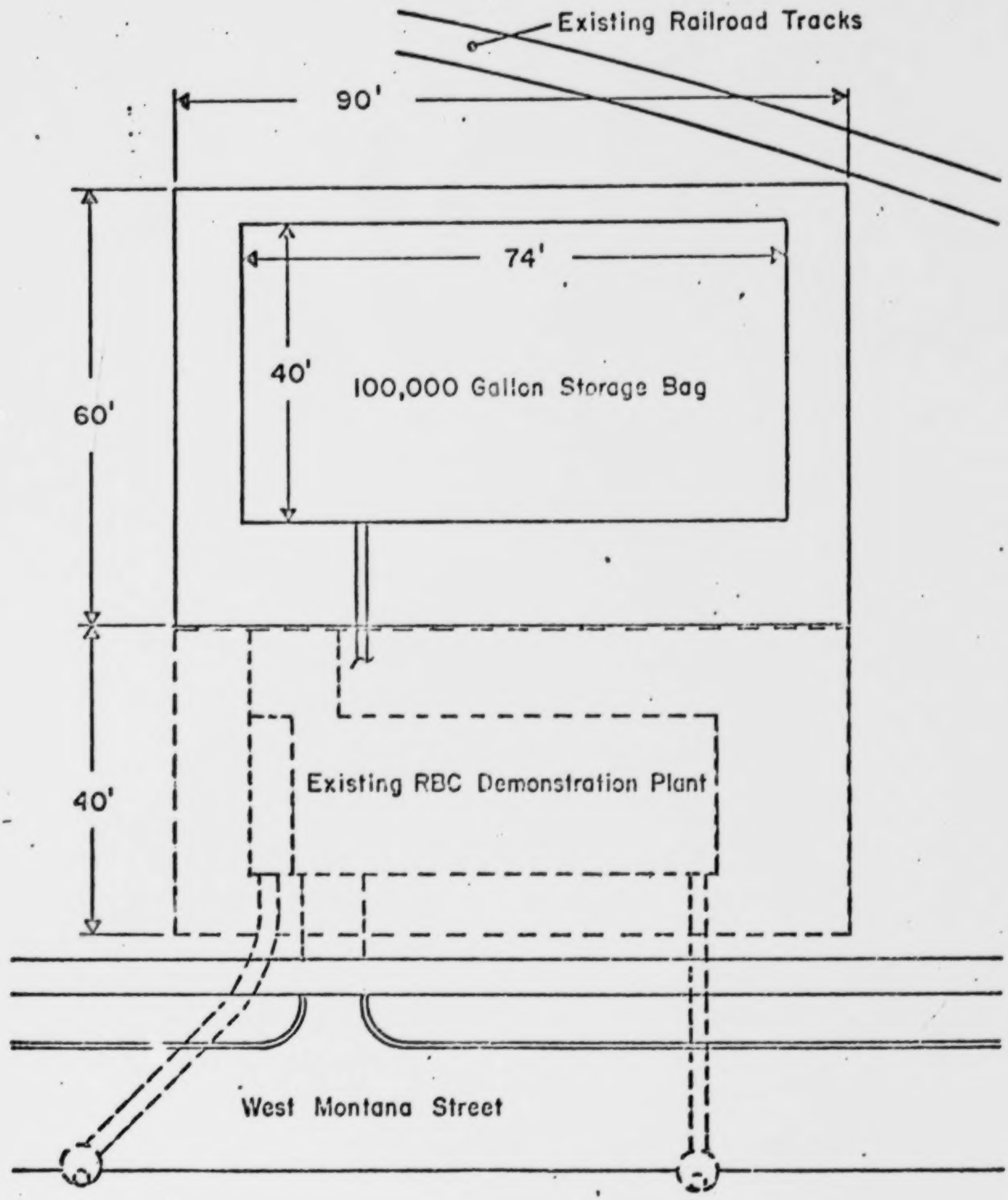

Existing Railroad Tracks
90'
74'
60'
40'
100,000 Gallon Storage Bag
40'
Existing RBC Demonstration Plant
West Montana Street

FIGURE 58

RBC PLANT SITE LAYOUT WITH
EXTERNAL STORAGE BAG

In conjunction with the above modifications, tilted-plate separators and pumps might be installed for the effluent. These units, (Figure 56) should have sufficient capacity so that the effluent could be fed through them at 10 DWF.

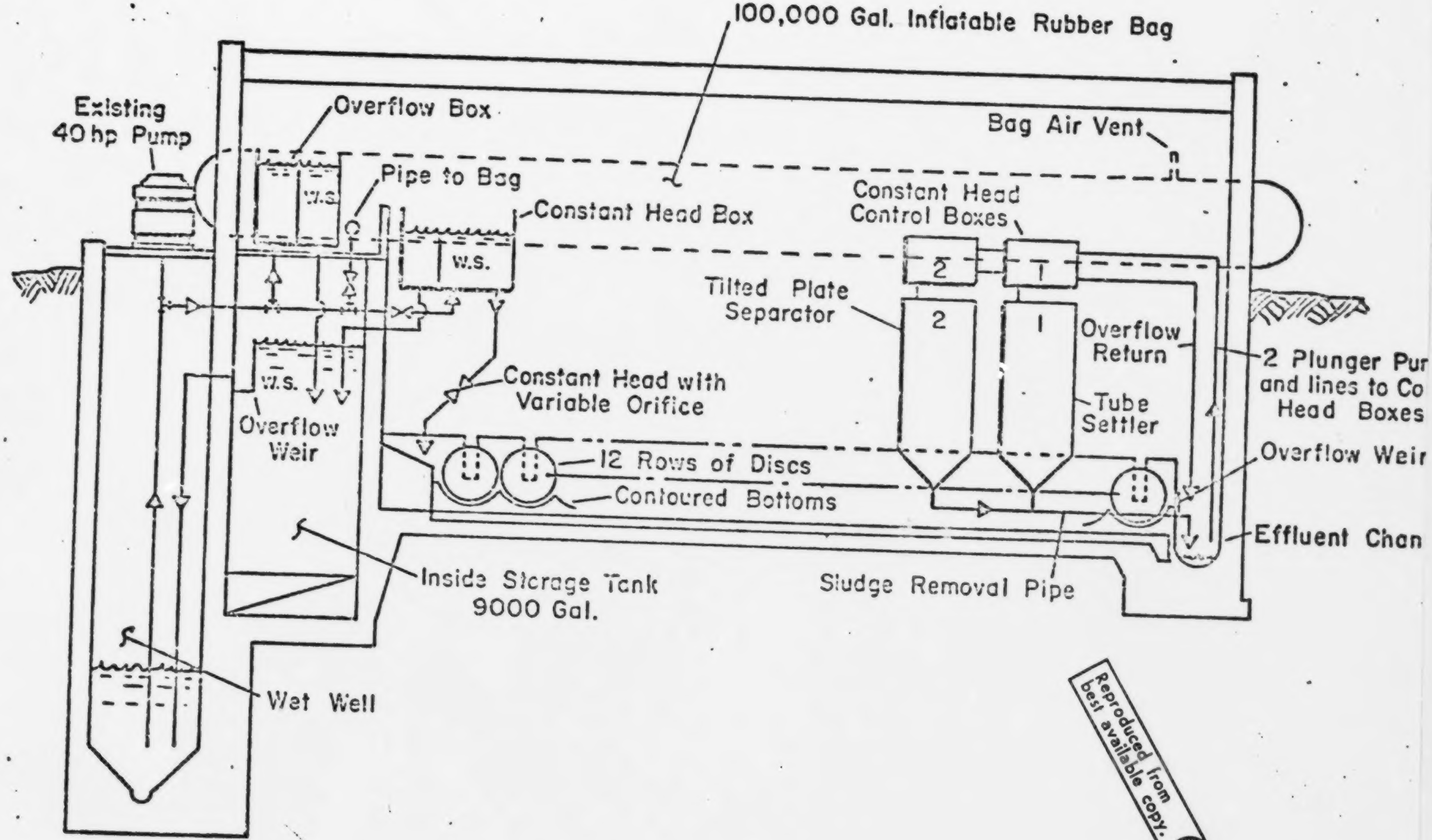
Functionally, the storage bag installed would be supplied from a low standpipe in the center of the bag. This arrangement would be best from the standpoint of construction cost, and the amount of solids that might have settled in the tank. A storm drain would be installed under the bag.

Figure 59 shows how these changes would apply to the demonstration plant in this project. The design could also be used for an underground RBC installation.

As discussed in earlier sections, a major portion of the organic load is transferable to the RBC system in 40 to 50 minutes. In the event of a holding tank or bag is employed for high hydraulic runoffs, a problem of storing putrescible solids under anaerobic conditions would exist if:

- There is a long retention time in the storage unit.
- Hydraulic flow is inadequate to rinse out all settleable solids, and
- Stagnant or holdup regions exist in the storage unit.

In view of the fact that anaerobic conditions could possibly occur, and create septic storage conditions, it would be necessary to establish a normal operating procedure for filling or emptying the storage units.


100,000 Gal. Inflatable Rubber Bag
Existing 40 hp Pump
Overflow Box
W.S.
Pipe to Bag
Constant Head Box
W.S.
Bag Air Vent
Constant Head Control Boxes
2
1
Tilted Plate Separator
2
1
Overflow Return
2 Plunger Pur
and lines to Co
Head Boxes
W.S.
Overflow Weir
Constant Head with Variable Orifice
Tube Settler
12 Rows of Discs
Contoured Bottoms
Overflow Weir
Effluent Chan
Inside Storage Tank 9000 Gal.
Sludge Removal Pipe
Wet Well

Reproduced from best available copy.

FIGURE 59.

PROPOSED FLOW SCHEMATIC OF THE RBC DEMONSTRATION PLANT WITH EXTERNAL STORAGE BAG AND FINAL CLARIFICATION

INTERNAL SYSTEM STORAGE

A review of alternative approaches for upgrading RBC plants, similar in design to the demonstration site, indicate an internal storage capacity of 30,000 ± 4,000 gallons could be made available with minimum system modifications. As shown in Figure 60, at a median rainflow of 1500 gpm, a 20 minute overflow period would be required to equal or exceed this storage potential. Sufficient volumetric capacity would, in this instance, be adequate to store the crucial 5 to 10 minute onset period of the rain events (7500 to 15,000 gallons).

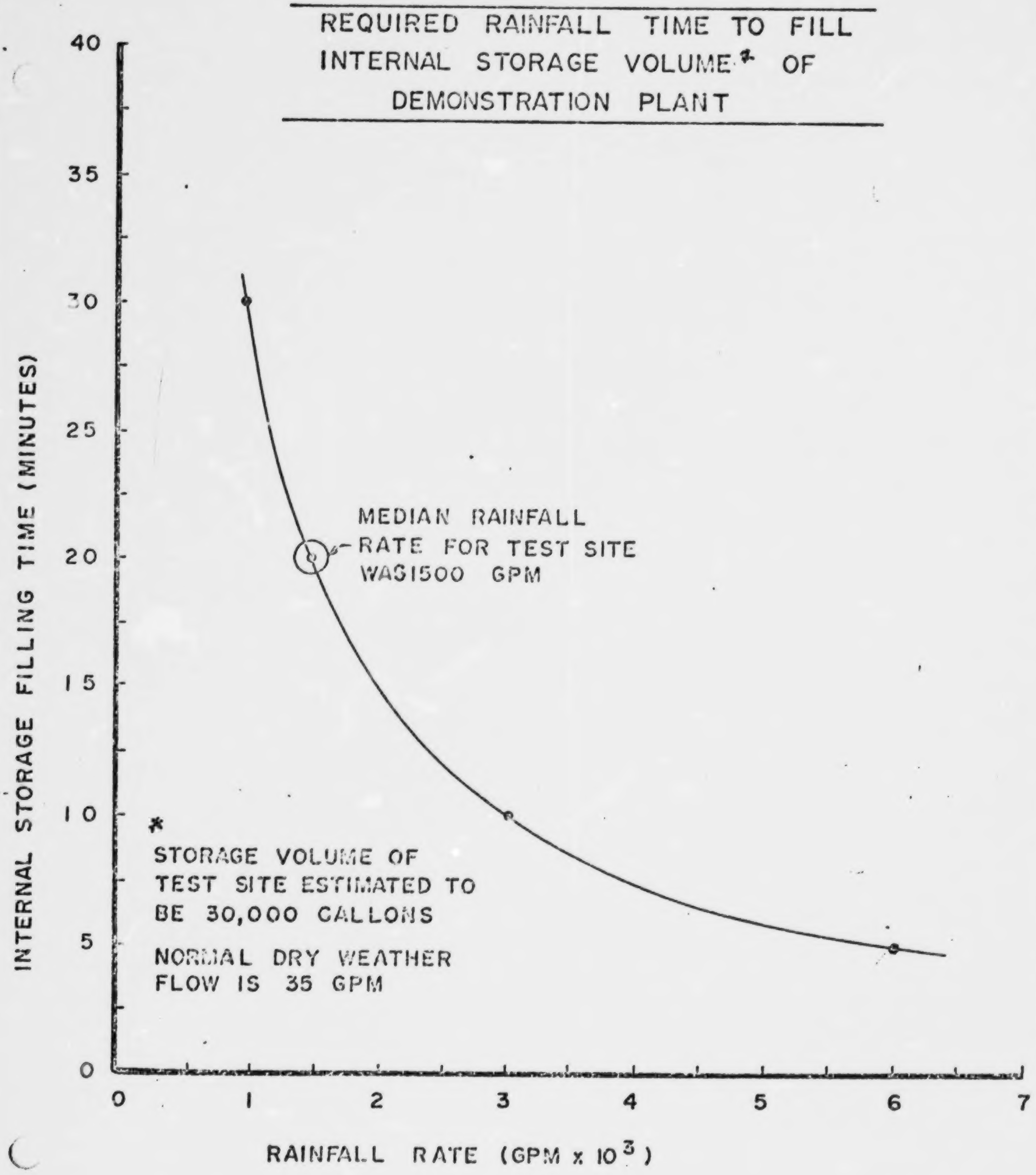
Modifications to the existing demonstration plant are illustrated in Figure 61 to achieve the design storage capacity of 30,000 gallons. Installation steps to accomplish this task are outlined in Table 8. A flow schematic and plan views are presented in Figures 62 and 63.

SEWER INTERCEPTOR STORAGE

Storm sewer interceptors already existing and large enough, could be modified for peak storm storage. Peaks of wet weather flow, exceeding the overload capacity of the RBC system, could be shaved by this storage volume. Excess peaks of very large rains, which cannot be stored temporarily, could be divided and partially discharged into the main treatment plant. A separate sludge pipe, installed inside the former sewer from the overflow point to the main treatment plant, would increase the versatility of the concept even more. The RBC configuration

FIGURE 60

TIME TO FILL INTERNAL STORAGE
VOLUME OF DEMONSTRATION PLANT

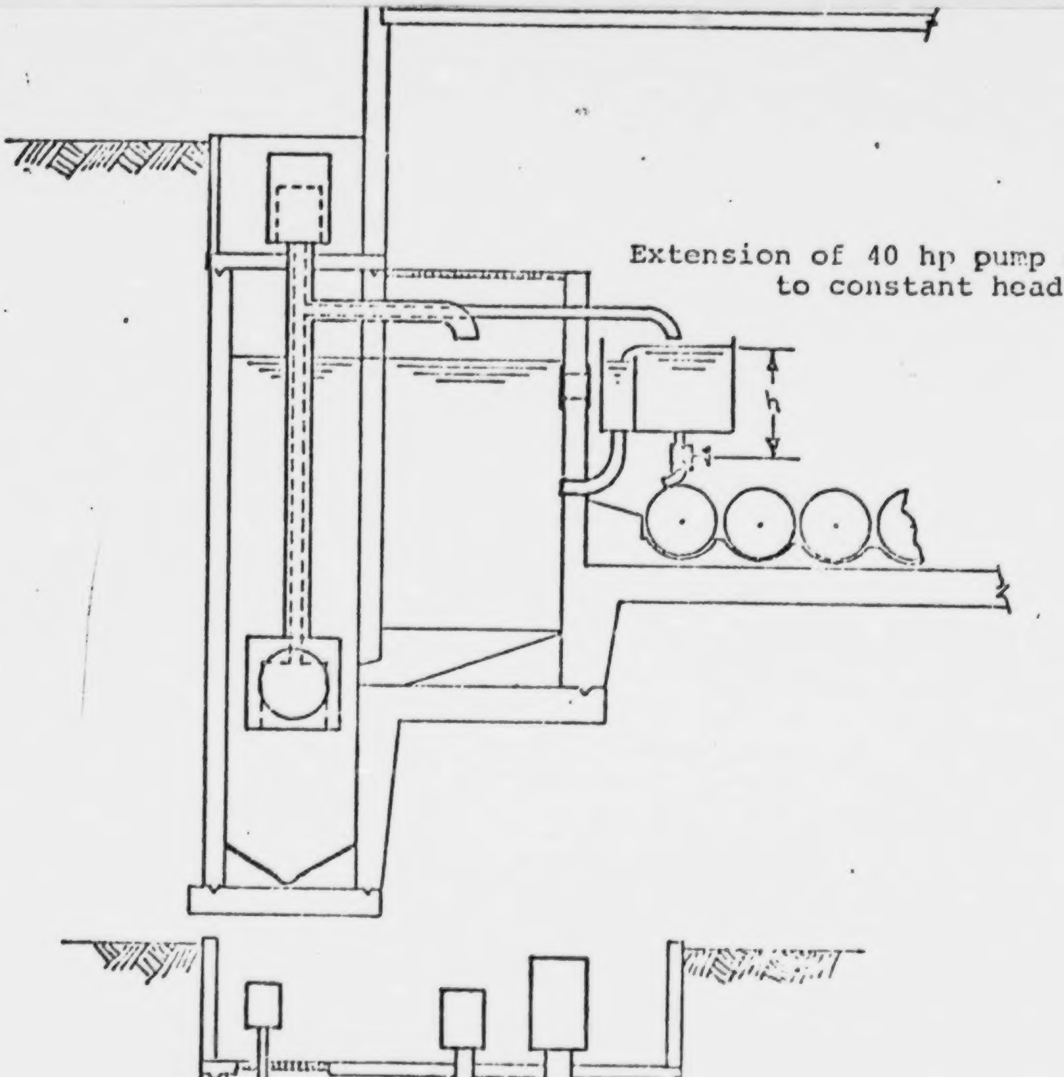


REQUIRED RAINFALL TIME TO FILL INTERNAL STORAGE VOLUME* OF DEMONSTRATION PLANT

* STORAGE VOLUME OF TEST SITE ESTIMATED TO BE 30,000 GALLONS

NORMAL DRY WEATHER FLOW IS 35 GPM

FIGURE 60



Extension of 40 hp pump outlet to constant head tank

Conduit extension and bypass valve, from pump well inlet to 75 hp pump.

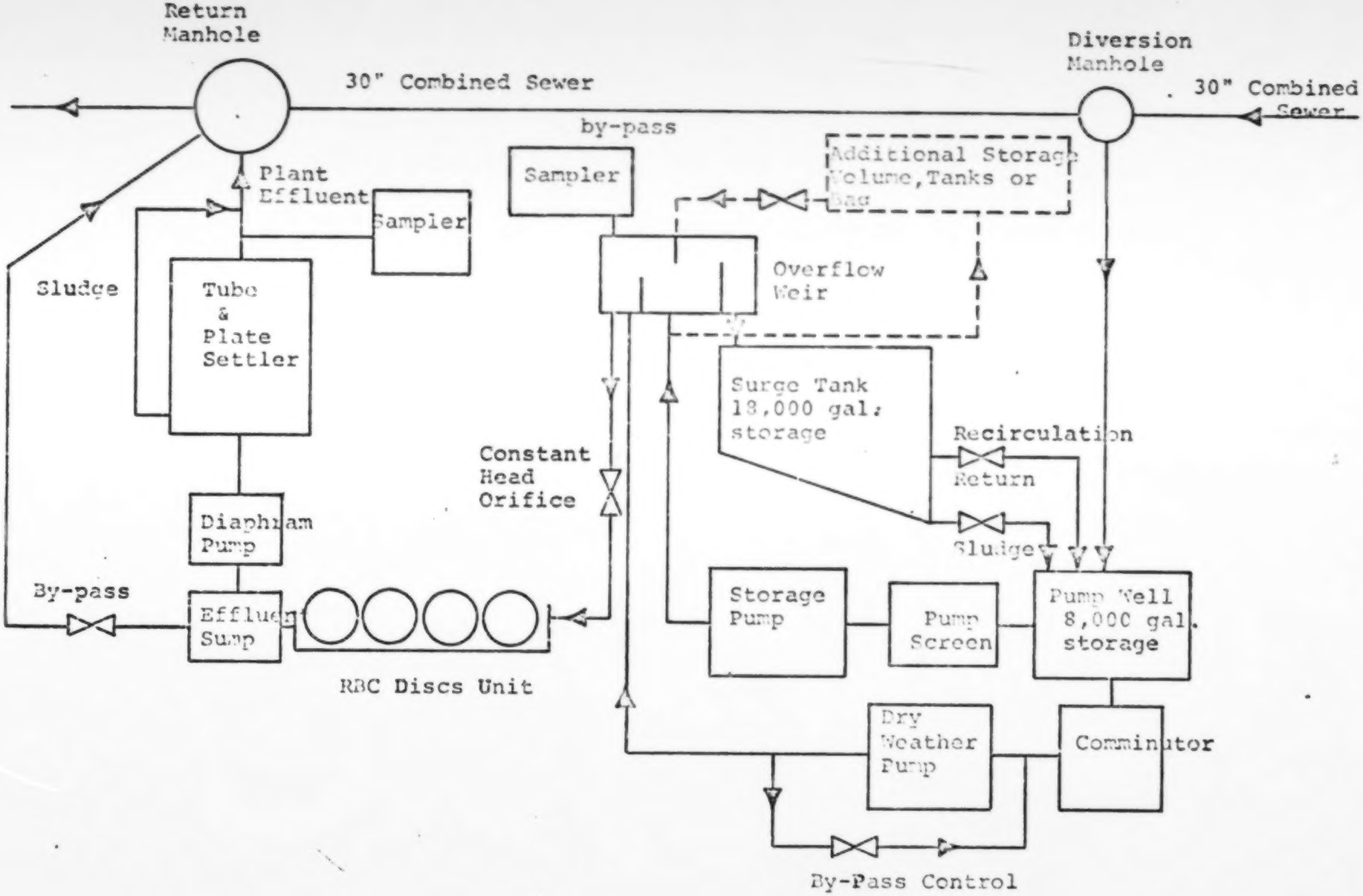
FIGURE 61
8TH & MONTANA STREET PUMP WELL,
MECHANICAL CHANGES

TABLE 8

INSTALLATION TASKS TO UPGRADE MONTANA STREET DEMONSTRATION UNIT

(See Figure 61)

1. Block off sewer inlet for period of renovation. (Should be positive to withstand 11' head)
2. Clean up pump chamber and adjacent surge area.
3. Clean and inspect 75-HP pump.
4. Connect inlet pump adapter and associated bypass check valve.
5. Install constant head tank and feedback piping.
6. Block off orifice openings.
7. Install 40-HP pump extension piping to constant head tank.
8. Install additional and revised controls, etc.
9. Block off flow and/or remove RBC units in South Bay.
10. Miscellaneous checkout, service, etc.
11. Open sewer inlet and place unit in operation.


Return Manhole
30" Combined Sewer
Diversion Manhole
30" Combined Sewer
by-pass
Sampler
Additional Storage Volume, Tanks or Bag
Plant Effluent
Sampler
Sludge
Tube & Plate Settler
Overflow Weir
Surge Tank 18,000 gal. storage
Recirculation
Return
Sludge
Constant Head Orifice
Diaphram Pump
By-pass
Effluent Sump
RBC Discs Unit
Storage Pump
Pump Screen
Pump Well 8,000 gal. storage
Dry Weather Pump
Comminutor
By-Pass Control

FLOW SCHEMATIC OF MONTANA STREET DEMONSTRATION PLANT WITH INTERNAL STORAGE

FIGURE 62

FIGURE 63

PROPOSED FLOW SCHEMATIC AND CROSS SECTION OF THE RBC DEMONSTRATION PLANT

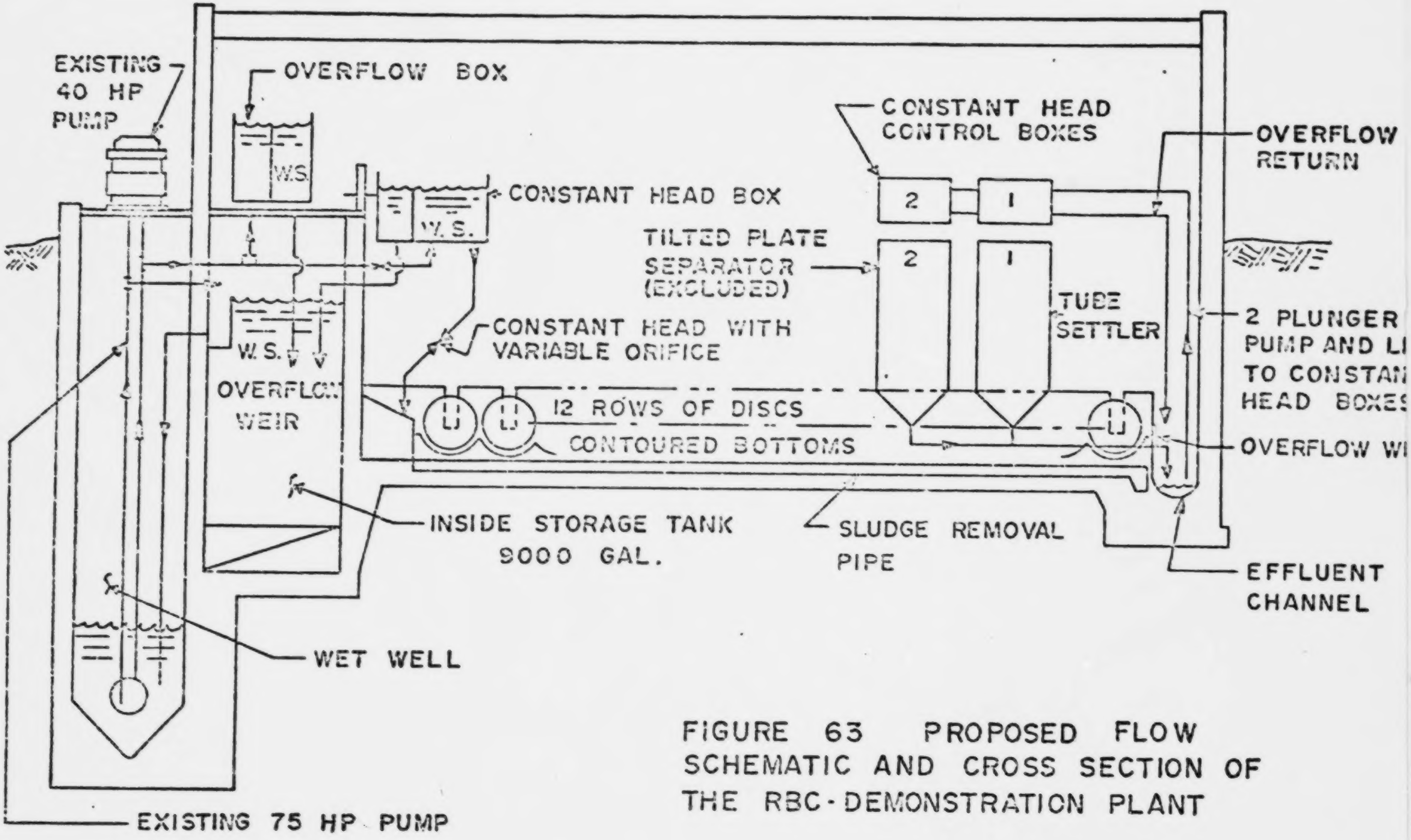

EXISTING 40 HP PUMP
OVERFLOW BOX
W.S.
CONSTANT HEAD BOX
W.S.
CONSTANT HEAD CONTROL BOXES
2
1
OVERFLOW RETURN
TILTED PLATE SEPARATOR (EXCLUDED)
2
1
TUBE SETTLER
CONSTANT HEAD WITH VARIABLE ORIFICE
W.S.
OVERFLOW WEIR
12 ROWS OF DISCS
CONTOURED BOTTOMS
2 PLUNGER PUMP AND LI
TO CONSTAN
HEAD BOXES
OVERFLOW WI
INSIDE STORAGE TANK 9000 GAL.
SLUDGE REMOVAL PIPE
EFFLUENT CHANNEL
WET WELL
EXISTING 75 HP PUMP

FIGURE 63 PROPOSED FLOW SCHEMATIC AND CROSS SECTION OF THE RBC-DEMONSTRATION PLANT

would, in effect, function much as described in Section X for the prototype RBC system.

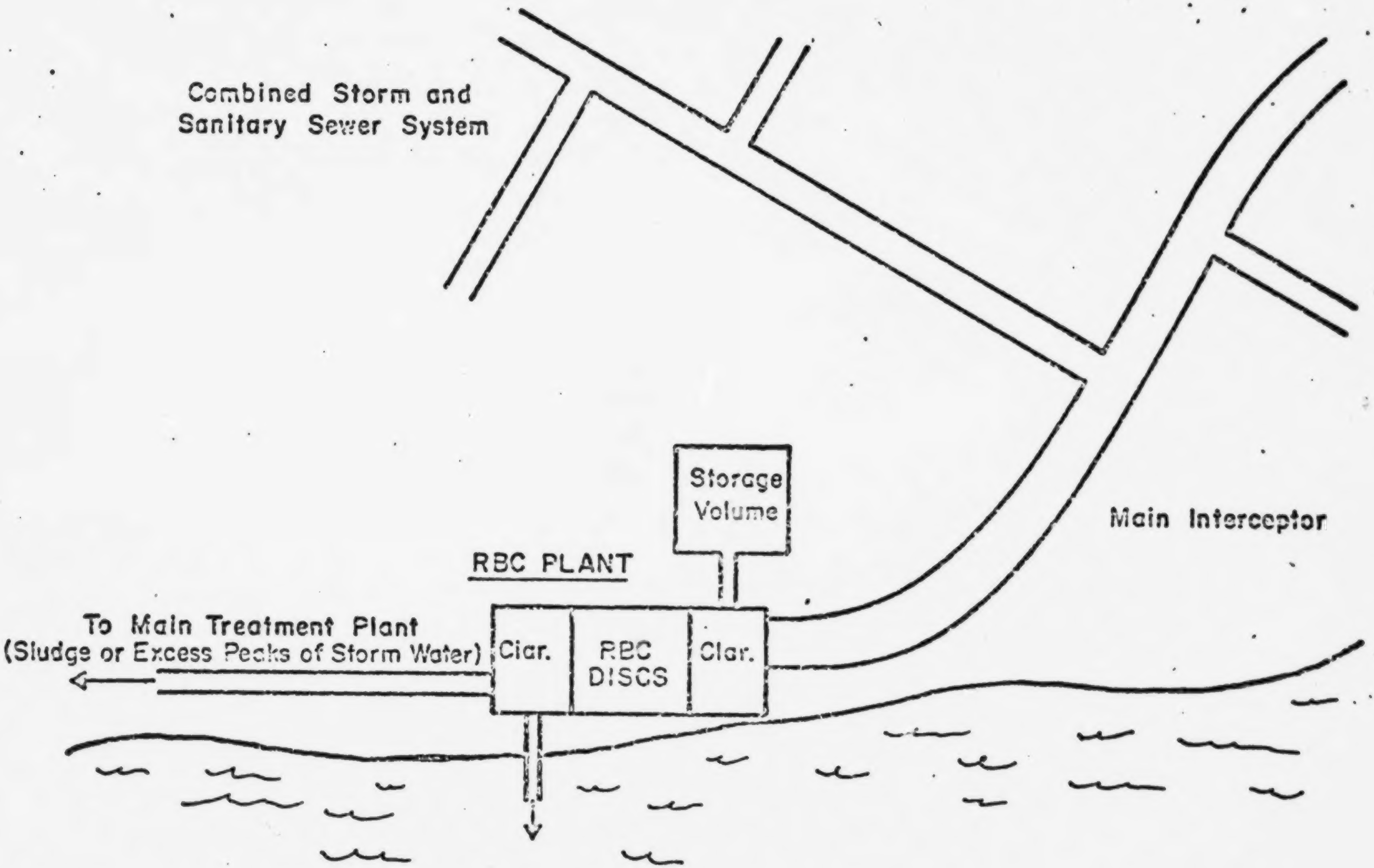
In Figure 64, a theoretical treatment system is shown based on peak shaving of rain events in the sewer interceptor. Diagrammatically, the flow of the combined sewer system is treated in an RBC plant located at a former overflow point. The effluent is discharged through the overflow, and the sludge is disposed of at the site, or pumped to the central treatment plant in the former sewer line.

This conceptual approach using an RBC system at the points of former storm overflows has the following advantages, namely:

- The main treatment plant receives continuously less hydraulic load than before.
- Peaks of rain events are smoothed out, and, thus, can be treated by a relatively small RBC unit.
- Overflows of untreated sewage can be eliminated.
- The RBC installations work dependably with little maintenance.

SLUDGE AND SOLIDS REMOVAL

Within the scope of this program, the major effort of this program related to the capability of the RBC system to biologically treat the organic pollutant that would exist in any combined sewer overflow. Just as the need for effluent settling equipment was identified likewise, the need for sludge handling equipment and/or controlled


Combined Storm and
Sanitary Sewer System
Main Interceptor
Storage
Volume
RBC PLANT
To Main Treatment Plant
(Sludge or Excess Peaks of Storm Water)
Clar.
RBC
DISCS
Clar.

TYPICAL INSTALLATION OF RBC-PLANTS IN A COMBINED SEWER SYSTEM

FIGURE 64

abatement procedures are needed. A number of programs for the abatement of sludge/or solid particulate from combined sewer overflow have been or are being investigated under other EPA funded programs. Design data from these units will provide useful data for designing a total system concept for the RBC process.

SECTION IX

CONCEPTUAL COMBINED STORM RBC SYSTEM

GENERAL

As stated in the literature, interceptor and trunk sewers are normally designed for capacities of two to three times dry weather flow. Runoff capacities sufficient to accommodate infiltration would nominally be in the range of 8 to 10 times dry weather flow. Therefore, increasing sewer capacity solely to accommodate excessive infiltration of storm water is obviously not a satisfactory solution in itself.

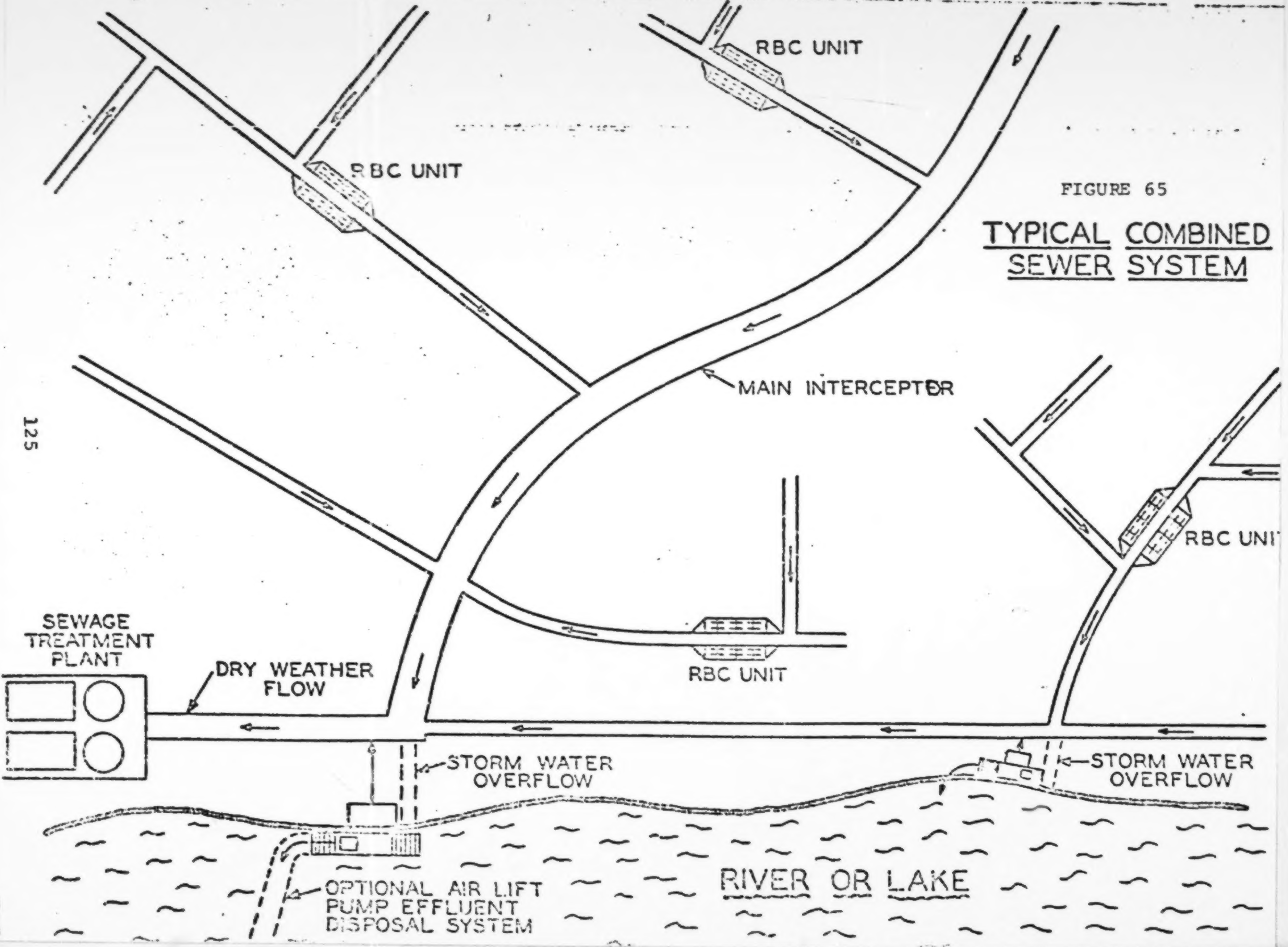
Data from the demonstration plant indicated that the RBC process can, in fact, effectively handle hydraulic runoffs of 14 times dry weather. As indicated previously (See Figure 52) for a span of 6 to 14 hours, a COD (BOD) reduction of 70% ± 8% was maintained by the RBC. To achieve higher levels of organic reductions, it requires only that additional surface area be made available for any proposed combined-storm RBC system. An RBC system designed to treat a specific multiple dry weather flow level (peak flow to dry weather flow ratio) would yield organic reductions of at least 10 to 15% higher under actual dry weather flow conditions.

DOWNSTREAM AND UPSTREAM INSTALLATIONS

Figure 65 shows conceptual approaches to RBC storm sewer applications either upstream or downstream of storm sewers.

FIGURE 65

TYPICAL COMBINED SEWER SYSTEM


RBC UNIT
RBC UNIT
MAIN INTERCEPTOR
RBC UNIT
RBC UNIT
SEWAGE TREATMENT PLANT
DRY WEATHER FLOW
STORM WATER OVERFLOW
STORM WATER OVERFLOW
RIVER OR LAKE
OPTIONAL AIR LIFT PUMP EFFLUENT DISPOSAL SYSTEM

The first approach would have RBC units installed at various locations upstream from the sewer overflow in conjunction with an existing combined sewer. In general, the RBC system would biologically treat the combined sewage and thereby increase the flow capacity of the sewer system under overflow storm conditions.

Alternatively, a second approach would be to install RBC units at the discharge of the combined sewer overflow to provide primary treatment and sterilization of the effluent. The primary stage of the system would consist of screening the overflow through coarse and fine screens, and grit removal, followed by sterilization of the effluent with chlorine or ozone, then discharge to the receiving body of water.

Shown in Figures 66 and 67 are more detailed illustrations of the two conceptual RBC systems. The process may be adjusted to utilize the existing combined sewer as shown in the alternate method or else a section of the sewer can be replaced by the RBC unit. For the RBC unit, a minimum of 2 stages are required; although 3 or 4 are employed to aid in smoothing out erratic organic and hydraulic surges.

In both approaches, it is proposed that during dry weather flow, one section would be filling and treating waste, while the other section would be draining and thereby, flushing the downstream sewer. Where there was a power failure or a high water level, sensors would be activated,

FIGURE 66

COMBINED SEWER OVERFLOW TREATMENT

SMALL INSTALLATIONS

COMBINED SEWER OVERFLOW TREATMENT
SMALL INSTALLATIONS

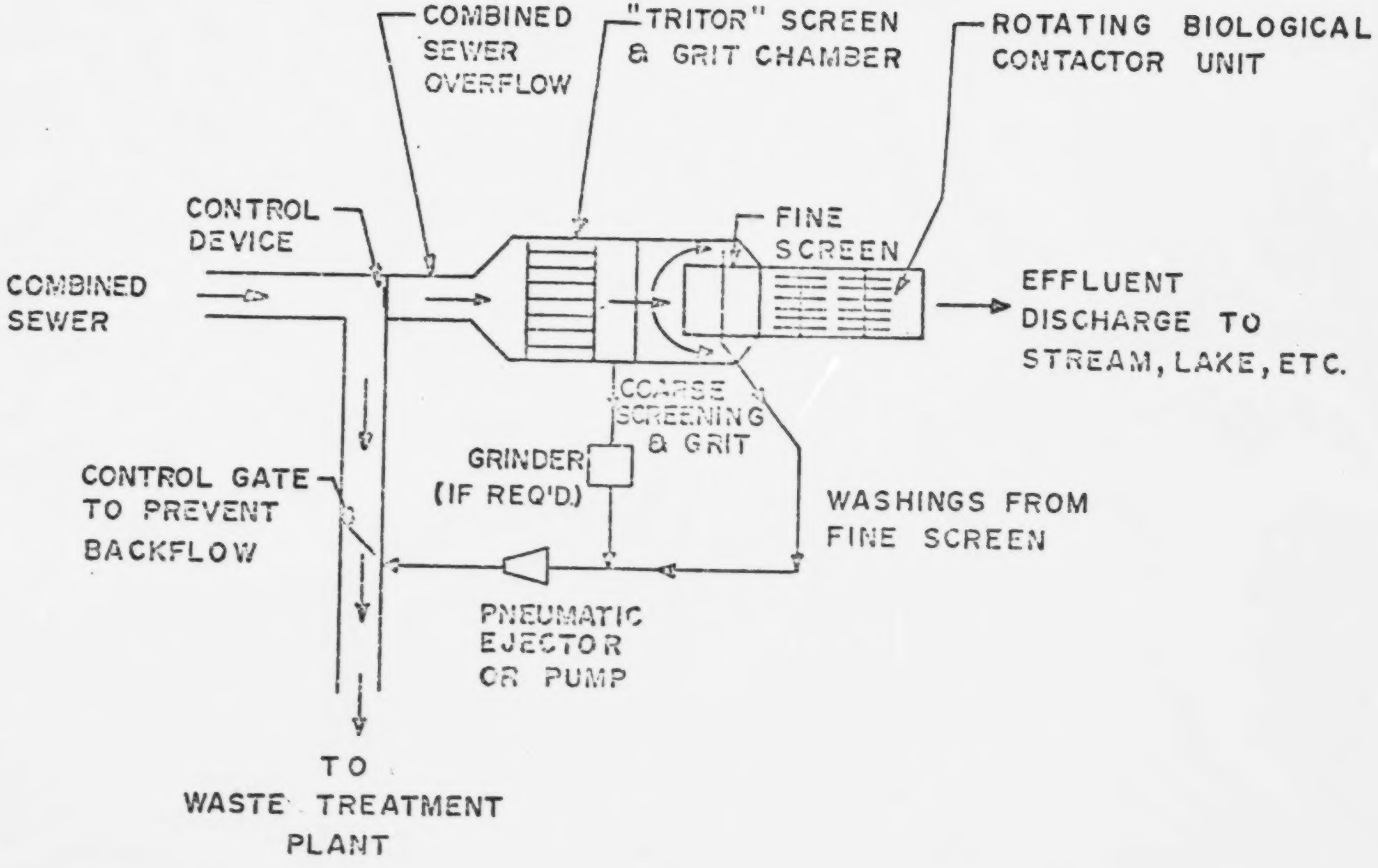

COMBINED SEWER OVERFLOW
"TRITOR" SCREEN & GRIT CHAMBER
ROTATING BIOLOGICAL CONTACTOR UNIT
CONTROL DEVICE
COMBINED SEWER
FINE SCREEN
EFFLUENT DISCHARGE TO STREAM, LAKE, ETC.
COARSE SCREENING & GRIT
GRINDER (IF REQ'D.)
CONTROL GATE TO PREVENT BACKFLOW
WASHINGS FROM FINE SCREEN
PNEUMATIC EJECTOR OR PUMP
TO WASTE TREATMENT PLANT

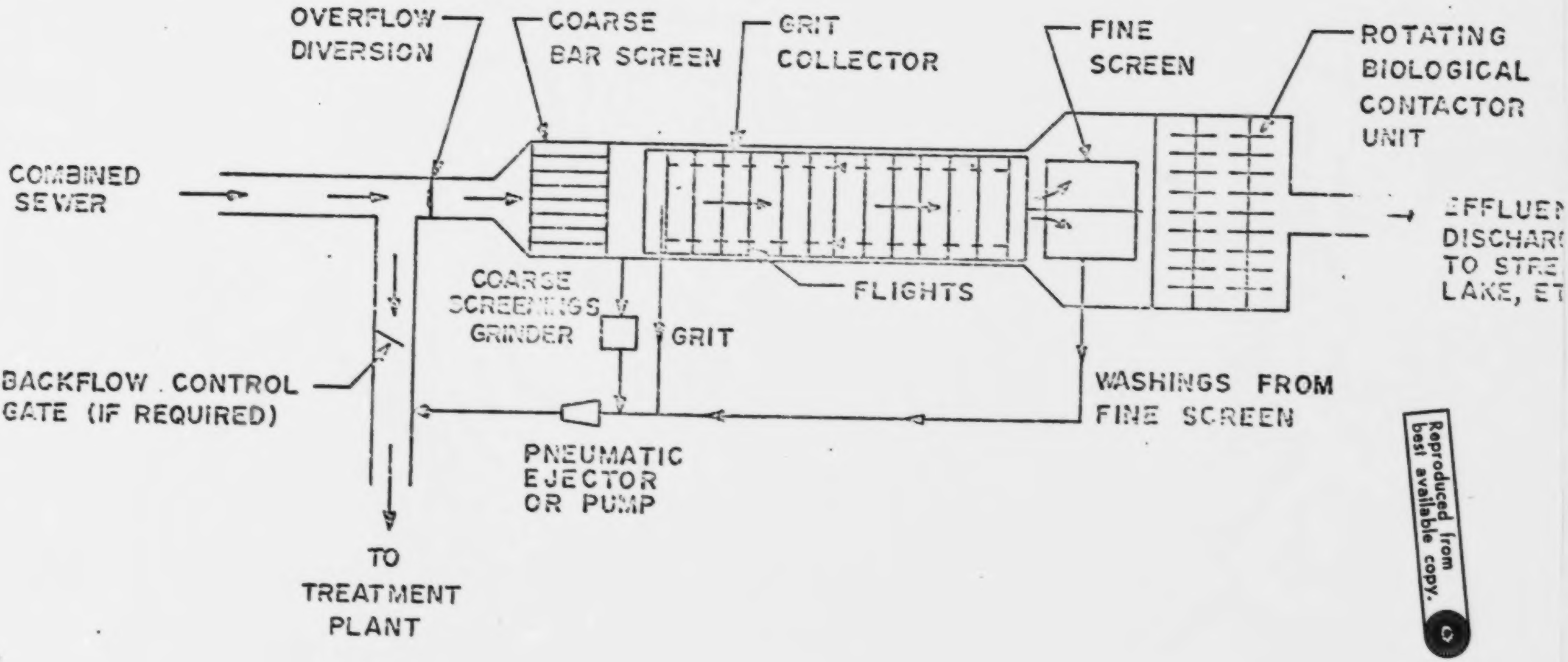
FIGURE 66

FIGURE 67

COMBINED SEWER OVERFLOW TREATMENT

LARGE INSTALLATIONS

COMBINED SEWER OVERFLOW TREATMENT
LARGE INSTALLATIONS


OVERFLOW DIVERSION
COARSE BAR SCREEN
GRIT COLLECTOR
FINE SCREEN
ROTATING BIOLOGICAL CONTACTOR UNIT
COMBINED SEWER
EFFLUEN
DISCHAR
TO STRE
LAKE, ET
FLIGHTS
COARSE SCREENINGS GRINDER
GRIT
BACKFLOW CONTROL GATE (IF REQUIRED)
WASHINGS FROM FINE SCREEN
PNEUMATIC EJECTOR OR PUMP
TO TREATMENT PLANT

Reproduced from best available copy.

FIGURE 67

all gates would automatically open thereby preventing any sewage backup. In effect, this would provide for "fail-safe" operation of the gates.

At overflow conditions flooding of the entire RBC complex would not harm the bacteria flora of the RBC discs or reduce unit efficiency. In this regard, it should be noted that the RBC system has a capitive bacterial mass which can provide up to 40 sq. ft. of active surface area per cubic foot, and has an equivalent mixed liquor suspended solids (M.L.S.S.) value of approximately 25,000 mg/l.

This large and active bacterial population thus, makes it possible to operate the RBC system at short retention times or high peak to dry weather flow ratios as noted previously.

Screening and grinding of the sewage would continue as would grit removal due to the decrease in velocity in the RBC stages during those periods of heavy runoff. For small installations, as noted in Figure 66, the coarse screenings might be stored on site and the grinding would be done manually or automatically after each overflow period. In the case of larger systems (Figure 67), the grinding operation would be automated. The grinding sequence would be programmed on the basis of a given overflow rate to the "primary" system.

The RBC installations, as proposed to treat combined sewage, could be installed as needed throughout a municipality. Such installations would be constructed underground and at chosen locations which would not seriously disrupt industrial or normal population activities.

ADVANCE RBC DISC DESIGN FOR COMBINED STORM SEWER SYSTEMS

Autotrol Corporation, since the completion of this demonstration project, has developed and substantially improved rotating surface media. The improved process equipment increases system packaging density and performance. The 28,000 ft^2 of surface area of the demonstration plant was installed on 24 disc shaft assemblies. With current commercial equipment, the same surface area is contained on a single 10 foot long RBC shaft. Single RBC (BIO-SURF) lengths are also available up to 25 feet in length and containing nearly 100,000 square feet of surface area. Total plant land area (RBC only) would be approximately 300 square feet as compared to 1300 square feet for the demonstration plant at 8th and Montana.

Figure 68 shows a typical view of this RBC shaft assembly. Figure 69 illustrates comparative performance for domestic waste at various hydraulic loading rates. The increased surface density and improved manufacturing process associated with the new media will also result in substantial savings in cost for any size RBC storm sewer plant.

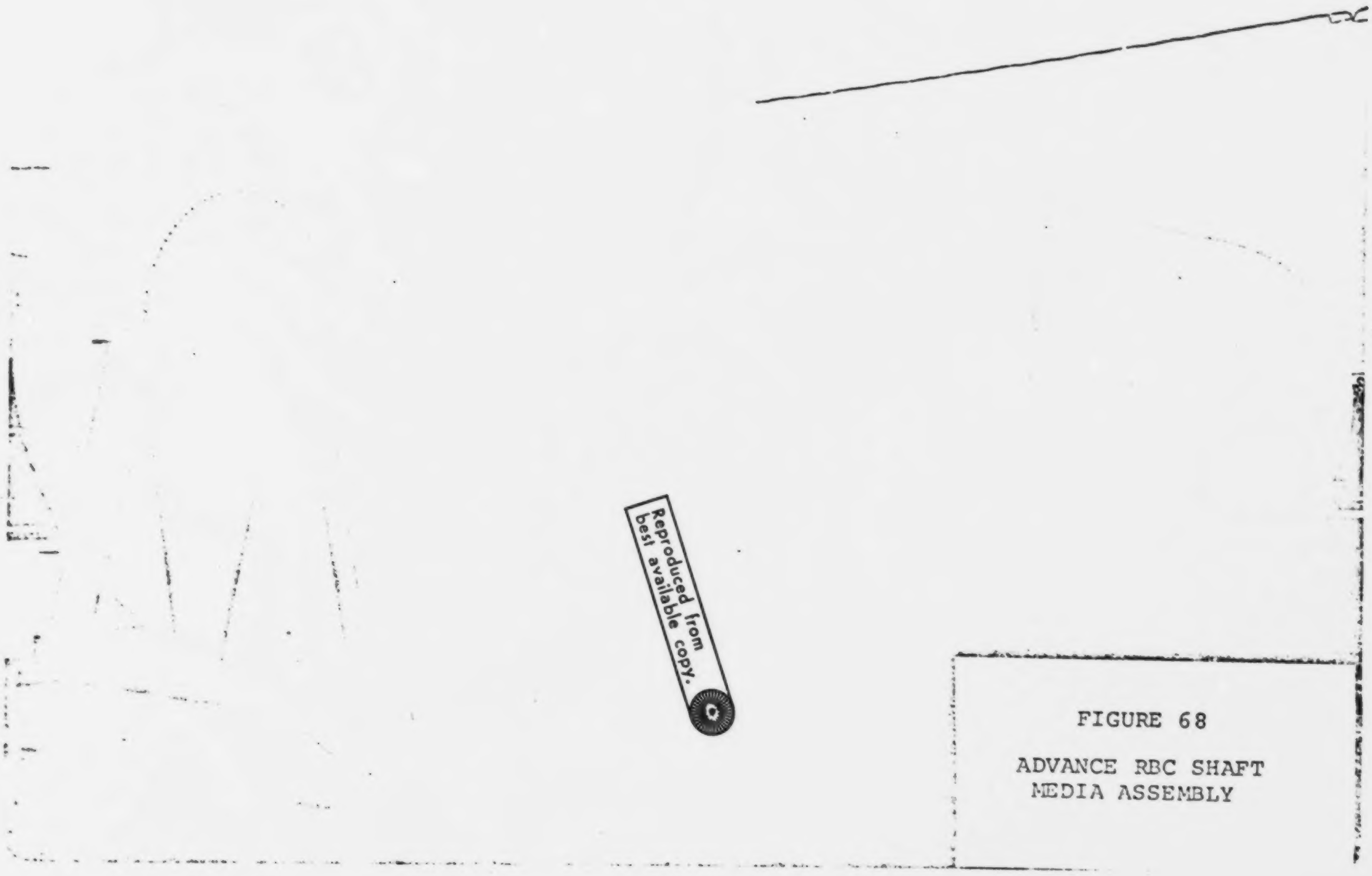


FIGURE 68

ADVANCE RBC SHAFT
MEDIA ASSEMBLY

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COMPARATIVE RBC SYSTEM PERFORMANCE

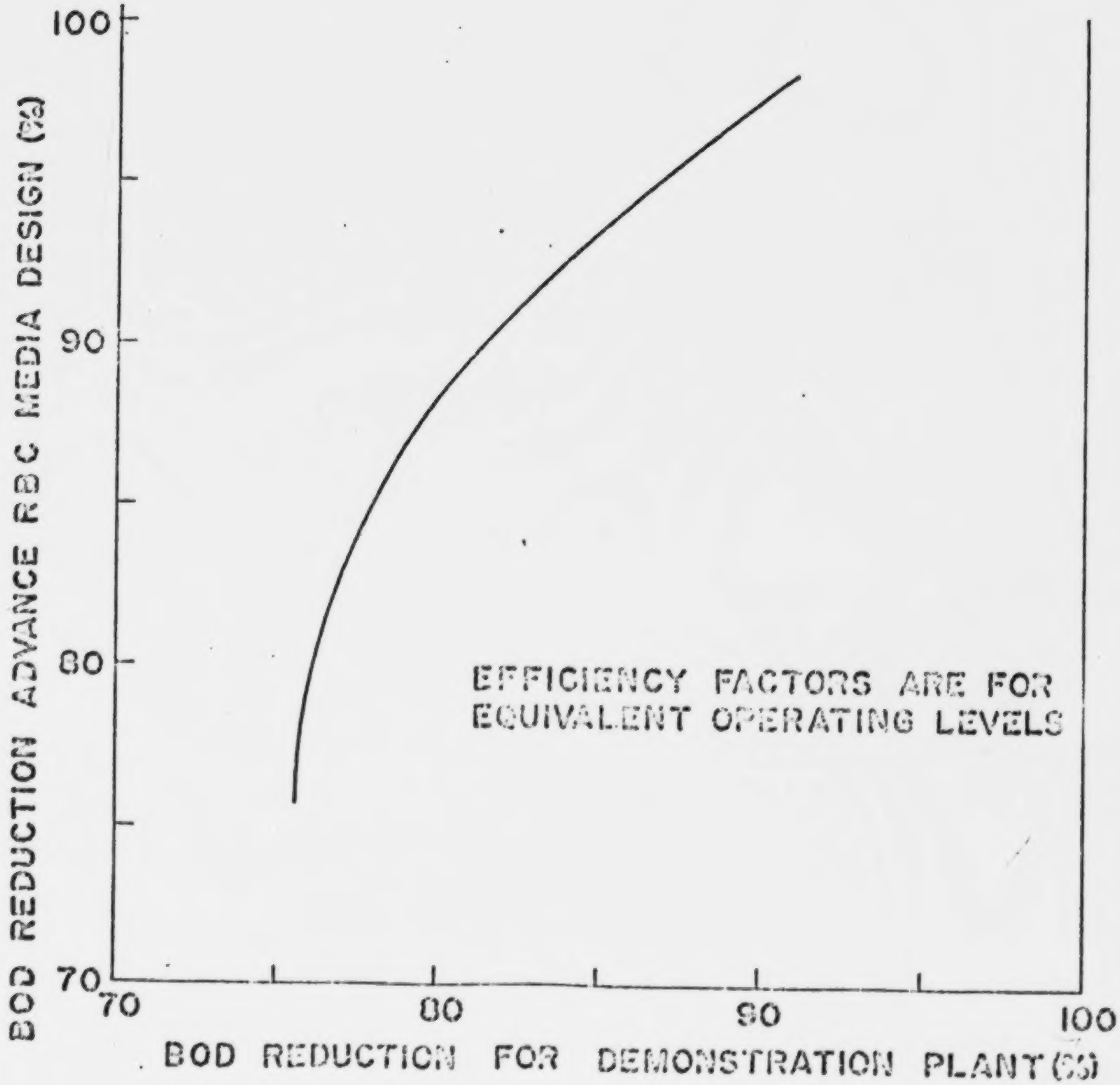

FIGURE 60

FIGURE 69

RBC PERFORMANCE

DEMONSTRATION PLANT

VS

ADVANCED RBC MEDIA

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In summary, the proposed RBC approaches would partially or completely accomplish the listed functions for reducing the pollution caused by combined sewer overflows; namely:

- Provide temporary storage of discharges.
- Ground water infiltration elimination.
- Increase the hydraulic capacity of existing combined sewer systems.
- Sewer flushing and cleaning.
- Chemical sedimentation improvements.
- Aerate sewage during low flow periods.
- Various methods of treatment to improve overflows, aesthetically and bacteriologically.
- Filtration and screening of overflow.
- Hydraulic and organic flow reduction.
- Produce a bacterial floc that would continue to degregate organic matter downstream from the installation.
- Substantially improve the quality of the storm water overflow.

Conceptually, the alternative RBC approaches have the advantage of simplicity, low capital costs, and operational flexibility.

SECTION X

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(Right-hand, odd-numbered page)